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JOURNAL OF PALEONTOLOGY, VOL. 8, NO. 4, PP. 393–416, PLS. 49–50, DECEMBER, 1934

EVOLUTION OF PTEROTOCRINUS IN THE EASTERN INTERIOR BASIN DURING THE CHESTER EPOCH

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ABSTRACT

The evolution of *Pterotocrinus*, an aberrant and highly specialized genus of camerate crinoids, is traced. Under the influence of the rapidly and constantly changing conditions in the Eastern Interior Basin, *Pterotocrinus* evolved into a large number of species most of which are grouped into three principal evolutionary lines or "gentes." The genus is shown to have started in early Chester time, to have expanded into the greatest number of species during the middle Chester, and to have continued until the close of the Mississippian period. The possible ancestry of the genus is discussed. The practical value of certain species as stratigraphic markers in the Chester (Upper Mississippian) series is pointed out. Thirteen new species are defined and thirteen earlier described species are redescribed, bringing into one paper all that is known to the writer concerning this genus.

The study on which this paper is based was initiated because of the desirability of more definitely outlining the distribution and range of the several species of *Pterotocrinus* as stratigraphic markers in the Chester series of the Eastern Interior Basin. Any one who has worked with this highly variable series of rocks realizes the value of any reliable index fossils which can be used in the identification of the various limestone formations of the Chester. *Pterotocrinus*, because of the rapid evolution through which it passed during the Chester epoch, developed into a number of definitely delimited species which are admirably suited for correlation purposes.

This paper is based on a study of the numerous specimens in the collection at Walker Museum, the University of Chicago, and the rather extensive collections made by the writer and his assistants during the past six field seasons in Kentucky. The excellent collection from Walker Museum contains the specimens secured by the late Stuart Weller over a period of sixteen field seasons as well as most of the Wm. F. E. Gurley collection. The writer wishes to express his appreciation for the loan of these specimens, and his thanks to Mr. H. L. Geis of the Department of Geology, University of Illinois, who has prepared the illustrations for the plates which accompany the descriptions.

STRATIGRAPHY

The Chester in the Eastern Interior Basin consists of an alternating series of sandstone and limestone-shale units, sixteen in all, although the maximum number in any one locality is fifteen. They crop out in eastern Missouri and across Mississippi River in St. Clair, Monroe, and Randolph counties, Illinois. The

continuity of outcrop is broken in Jackson County, Illinois, but beginning in southwestern Jackson County they extend as an almost continuous belt of varying width across southern Illinois, around the western Kentucky coal field, and northward into Indiana. Very little is known of the paleontology of these beds in Indiana and they have been studied paleontologically in a limited manner in Missouri. Most of the material for study has been collected in Illinois and Kentucky, and it is hoped that the results of the present study may be applicable to rocks of the same age in other portions of the country. Different names have been applied to these formations in different localities and in order to make clear the matters of nomenclature and correlation, the chart, Figure 1, has been introduced. No attempt is made to show thicknesses of the various formations.

DIAGNOSIS OF THE GENUS

Class CRINOIDEA Miller

Order CAMERATA Wachsmuth and Springer

Family HEXACRINIDAE Wachsmuth and Springer

Genus PTEROTOCRINUS Lyon and Casseday

Asterocrinus, LYON, *1857*, Geol. Rept. Ky., vol. 3, p. 472.

Pterotocrinus, LYON and CASSEDAY, *1859*, Am. Jour. Sci., vol. 29, p. 68.—MEEK and WORTHEN, *1866*, Geol. Rept. Ill., vol. 2, p. 288.—SHUMARD, *1866*, St. Louis Acad. Sci., Trans., vol. 2, p. 394.—WETHERBY, *1879*, Cincinnati Soc. Nat. Hist., Jour., vol. 2 (April number); *1879*, idem (October number).—ZITTEL, *1879*, Handbook der Paleontology, vol. 1, p. 365.—WACHSMUTH and SPRINGER, *1881*, Revision Palaeocr., Pt. II, p. 87; *1885*, idem, Pt. III, p. 120.—S. A. MILLER, *1889*, N. Amer. Geol. and Palaeontology, p. 276.—WACHSMUTH and SPRINGER, *1897*, The Crinoidea Camerata of North America, p. 791.—SPRINGER, 1926, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 47.

Calyx more or less turbinate with heavy plates unornamented except for protuberances in a few species. Dorsal cup bowl or saucer-shaped and wider than high, the ventral disk or tegmen pyramidal and higher than the cup. Five radially arranged, large, conspicuous plates or processes project out between the rays of the arms. Column round with a small axial canal. Basals two, pentagonal in outline; basal cup shallow and angularly excavated on the posterior and anterior sides for the reception of the anal plate and the anterior radial. The radials are wider than high and increase rapidly in width upward. Usually all the radials except the anterior one are subquadrangular in outline and truncate below, the anterior radial being angular below. The five primibrachs are small, triangular, and often hidden from outside view of the calyx and each supports two axillary secundibrachs which meet above the apex of the primibrachs with their lateral faces resting on the radials. The secundibrachs support on their sloping faces from four to twelve fixed tertibrachs in four vertical rows (all brachials between the secundibrachs and the beginning of the biserial arrangement of the arm plates are designated as tertibrachs in this paper). The outer tertibrachs of the proximal row touch with their outer faces the radials.

The dorsal cup possesses neither interradial nor interaxillary plates and as a rule only one anal plate[1] which is elongate, commonly subquadrangular, and considerably smaller than the radials. Usually it rises as high as or higher than

[1] Wachsmuth and Springer report in one specimen a small triangular piece above the regular anal plate. They regard this as of no structural value.

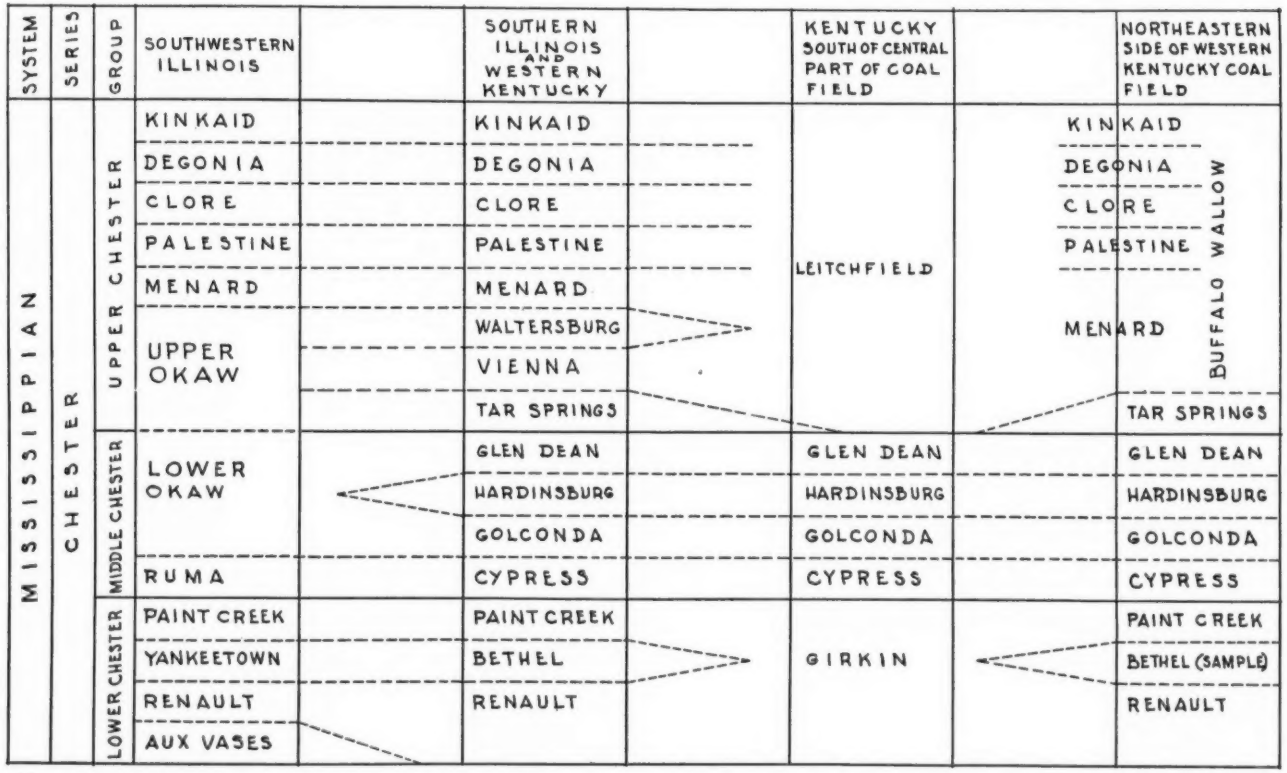

FIG. 1- GENERAL CHESTER CORRELATION IN THE EASTERN INTERIOR BASIN

the radials but in some species it is shorter than the radials. There are twenty short, biserial, simple arms arranged in groups of four, each group being separated into two compartments of two arms each by the appendages. The pinnules are short and in close contact.

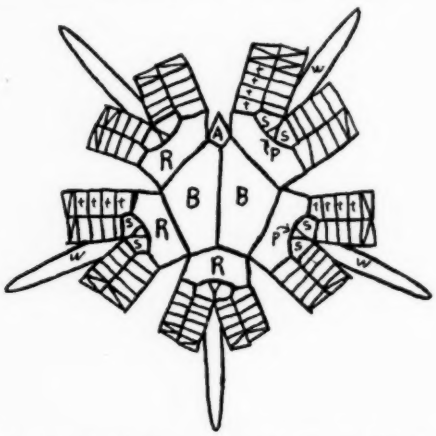

FIG. 2.—Analysis of the plates in *Pterotocrinus* Lyon and Casseday. Basals—B. Radials—R. Anal—A. Primibrachs—p. Secundibrachs—s. Tertibrachs—t. "Wing plates" or processes—w.

The tegmen is pyramidal, highly elevated and pentagonal in outline with the sides of the pyramid situated interradially and depressed longitudinally to form niches for the arms. The angles are excavated or pierced and support the large processes, "wing plates," or appendages. Four of the interradial spaces are approximately the same in size and composed of three to six oblong plates. The posterior space is widest and composed of a greater number of plates. The first interambulacral plate rests on the ends of two adjacent tertibrachs and between two secondary radial dome plates. Above the first interambulacral, others are distributed around the proximal ends of the appendages. The anus is nearly in the center and surrounded by many tiny plates which form a small protuberance or small cone. The oral plates are large and rest directly upon the interambulacrals with the posterior oral wedged between the other four.

The most striking and characteristic features of *Pterotocrinus* are the wing-like processes which probably represent the first radial dome plates. They are quite variable in form, some are spatulate, others cuneiform or scapuliform, some massive and rounded, and still other thin and knife-like or bifurcated. They rise to the top of or beyond the tegmen and extend laterally beyond it and the arms. They rest on the surface of the tegmen in pits or grooves along the edges of the inclined interradial and oral plates. Beneath the appendages, over each ray, there are two smaller radial secondary dome plates which rest against the plates of the dorsal cup inclosing a large interambulacral plate. The excavated upper edges of these plates form the lower ends of the sockets for the appendages. The ambulacra are subtegminal.

EVOLUTIONARY LINES OR GENTES

Pterotocrinus is very common in many of the Chester calcareous formations. The specimens are rarely complete being most often represented by the detached appendages or "wing plates." However, the variations in these specialized plates furnish the best characters for specific definition and it is practicable to describe species from the plates alone. The species herein described have been based on specimens exhibiting all the plates of the calyx, on the calyx exclusive of the appendages, or on specimens of the appendages only. All of the species included in the diagram (fig. 3) showing the relasionships have been based on specimens showing both the calyx and "wing plates" or on the plates alone.

In describing these plates it is essential to use names to distinguish the various parts of each. Since many of them resemble somewhat a leaf in outline, the terms used to designate parts of leaves have been used. The proximal heavier portion at the place of attachment is designated the "base," the outer

or distal expanded portion is called the "blade," and the narrower portion between the base and blade, when present, is referred to as the "petiole."

A careful study of the appendages of more than twenty species shows that they can be grouped into three major lines of evolution or development, each of which is designated as a "gens," and given the name of a typical species of the group. The term "gens" as here used denotes a group of species within a genus which are more closely related to each other than to any other species of the genus and appear to possess a common ancestor.

Pterotocrinus depressus gens.—The species of this gens are characterized by a greatly expanded blade portion of the plate which becomes thin and knife-like around the distal margin. The petiole is short or absent, the expansion into the thin blade portion beginning at or a short distance beyond the base or area of attachment. The petiole when present may occur on both sides of the plate or may be restricted to one edge, along the upper in some forms and on the lower in others. In some species the blade expands more or less equally both upward and downward while in other forms the expansion is much greater downward. In outline the plates vary from elongate oval to subovate and almost circular.

Pterotocrinus armatus gens.—This gens is characterized by the presence of a pronounced petiole portion approximately equal to one-half the entire length of the plate and by a rapidly expanding blade portion which becomes very thin in the distal portion. The blade varies in its expansion, in some species being more or less equal both upward and downward and in others much greater downward. Some of the species possess a thin petiole while in others this portion of the plate is massive, triangular in cross section and flat above, and still others possess a massive petiole which is rounded on the upper side.

Pterotocrinus spatulatus gens.—A greater diversity of forms has been included in this gens than in either of the other two, and possibly two species, *P. capitalis* (Lyon) and *P. coronarius* (Lyon) might be placed in a group separate from this. They have not been so placed because of the failure to detect in beds below the horizon in which they occur any forms outside the members of this gens from which they might have been derived.

The members of this gens are characterized by the absence of an expanded thin blade portion. In most of the forms the base is nearly as thick as the thickest portion of the plate which normally increases somewhat, being thickest about one-fourth of the length from the proximal portion. Beyond this point they become gradually thinner and terminate either in a point or in a thin spatulate portion. The above remarks hold true for all members of the gens except *P. capitalis* and *P. coronarius* which are thinnest at the base and become increasingly thicker toward the distal portion. *P. bifurcatus* follows the trend of the normal members of the gens for about half the length of the plate and then bifurcates, ending in two divergent prongs each of which has somewhat the shape of the appendage of *P. acutus*.

Pterotocrinus? primus Sutton, n. sp., the only recorded form from the Renault, is doubtfully referred to this genus. It has not been included in any of the above described gentes but has been considered as the possible ancestral form from which the others developed.

EVOLUTION OF *PTEROTOCRINUS*

The writer wishes at the outset to emphasize the fact that this does not represent the proved evolutionary changes in *Pterotocrinus*, but is rather the most probable relationship based on physical features and succession in time and possibly does indicate the genetic relationship in many or most cases. Obviously it is impossible for any worker with fossil forms to say definitely that a given species in one geological formation has evolved directly into another given spe-

cies in younger beds. The best that can be done in any case is to select those which, because of certain features, might most logically have evolved into latter forms.

Pterotocrinus in the Eastern Interior Basin lived during a time of constantly changing seaways and other environmental conditions. When the marine waters invaded this area as relatively clear, calcium carbonate depositing seas, the various marine animals migrated with the encroaching waters, living and developing here. When the waters retreated or were withdrawn the marine forms, of necessity, migrated with the retreats and during the times when the clastic Chester sediments were being deposited here these crinoids were living and developing elsewhere. With the succeeding invasions of the clear marine waters, *Pterotocrinus*, represented by forms modified during these intervals of time, returned to this basin as different and distinct species. This alternation of different conditions with the times of development elsewhere makes it possible to separate the forms preserved in the various calcareous formations. In tracing the development of such a genus, these unrecorded intervals in its development prevent determination of all of the changes through which it passed. However, it is possible that if the record of *Pterotocrinus* were complete such a separation into distinct species might be impossible because of the numerous intergrading forms which should be expected.

Pterotocrinus is a highly differentiated and aberrant form which is most like typical Camerata in the relative large fixed brachials which to the third order, tertibrachs, are incorporated in the calyx. This feature, however, is unlike typical Hexacrinidae which do not have the tertiary brachials in the calyx.

The ancestral form from which *Pterotocrinus* developed has not been definitely determined. *Pterotocrinus* is most like *Talarocrinus* which preceded it in time and became extinct during the Paint Creek stage, the beginning of the rapid development of *Pterotocrinus*. The structural features of the two genera trend in the same general direction but are slightly developed in *Talarocrinus* in contrast to the great development in *Pterotocrinus*. The ancestry very probably goes back through *Talarocrinus* to *Dichocrinus*. The line of modification of *Dichocrinus* which may have led to the two later genera consisted of increase in the tegmen at the expense of the dorsal cup and arms. The chief regressive modifications consist of shortening of the arms and decrease in size of the radials, primibrachs, and anal plate. The major development occurs in the ambulacral areas where the axillary plate or radial dome plate is developed into a great variety of forms, the conspicuous appendages of *Pterotocrinus*. The essential calyx elements of *Pterotocrinus* and *Talarocrinus* are the same as in *Dichocrinus*, and *Talarocrinus* is intermediate both in time and structure between the other two genera. A much more detailed discussion of these changes may be found in Springer's article.[2] The major modifications while only feebly developed in *Talarocrinus* attain the height of extravagance in *Pterotocrinus*, the last genus of the Hexacrinidae, and the aberrant features may well forecast the near extinction of the family.

Pterotocrinus, as far as known, is limited in its geological range to the Upper Mississippian or Chester series. Some species are known from areas other than the Eastern Interior Basin and it is possible that further study may discover localities not heretofore known and lead to more definite conclusions in regard to paleogeography during the Chester epoch.

The oldest known species of the genus is *Pterotocrinus* (?) *primus* from the Renault limestone of Hardin County, Illinois. This form is represented by only one incomplete specimen and is doubtfully referred to the genus. If it is a *Pterotocrinus*, it may well represent the ancestral form from which the main lines

[2] Springer, Frank, Unusual forms of fossil crinoids: *U. S. Nat. Mus., Proc.*, vol. 65, art. 9, pp. 45–46, 1926.

of evolution developed. All three of the main lines of development or gentes occur in the Paint Creek formation, the second limestone of the Chester. None of the forms are large and all display primitive characters. *P. arcuatus* Sutton, n. sp., shows one of the longer petiole portions of any member of the *P. depressus* gens, but is placed at the beginning of this gens even though the petiole is relatively long, because the plate is thin and the petiole is considerably shorter than that of *P.* (?) *primus* of the Renault and other Paint Creek species and indicates the general trend toward shortening of this portion of the plate, a feature which has been considered as distinctive of the gens. *P. convexus* Sutton, n.sp., of the *P. armatus* gens, still possesses a simple, regular, relatively long petiole portion and only a moderately flaring blade while *P. elongatus* Sutton, n.sp., of the *P. spatulatus* gens has only an inconspicuous flaring of the blade and retains the tendency toward constriction immediately beyond the base, a feature which becomes lost in the younger members of the gens to which it is assigned.

The greatest diversity of species and most extravagant development of the genus are attained in middle Chester time. Springer states that *Pterotocrinus* is characteristically a genus of the upper Chester, but this is due to his inclusion of the Golconda and Glen Dean in the upper Chester, contrary to the accepted classification of these formations in the middle Chester.[3] In both the Golconda and Glen Dean limestones, *Pterotocrinus* is represented by large numbers of species. The tendency during this stage was toward large, massive, heavy "wing plates" or processes, with a wide variety of form. In the Golconda, the *P. depressus* gens is represented by forms in which the petiole portion has been much shortened or entirely abandoned and the typical *depressus* shape is approached in the main line of ascent. This gens continues throughout the remainder of the Chester series with forms which vary only in minor respects. The species of the *P. armatus* gens show a notable increase in thickness of the petiole portion of the plate, this part in most forms becoming heavy, triangular or wedge-shaped in cross section and flat on the upper side in the Golconda forms. The Glen Dean species differ from those in the Golconda chiefly in the development of a rounded upper edge of the petiole and an increase in the massiveness of the basal and petiole portions of the plate. This gens is not known in formations younger than the Glen Dean.

The main line of development of the *P. spatulatus* gens is represented by *P. abruptus* Sutton, n.sp., in the Golconda and *P. spatulatus* Wetherby in the Glen Dean. No related forms are known from either the higher Vienna or Clore limestones but the gens must have been in existance during these times since it is represented in the Menard formation by *P. subspatulatus* Sutton, n.sp., and by an unnamed species in the Kinkaid. The greatest development comes in what are considered divergent lines. The first of these offshoots is represented by two species, *P. capitalis* and *P. coronarius* in the Golconda, a line which must have started during Cypress time in some area other than the Eastern Interior Basin since these species are characteristic of the lower Golconda. The appendages of both are heavy and massive and increase in thickness from the base to the distal portion in contrast to the typical members of the gens which thicken for a distance and become thinner toward the distal extremity. This branch of the gens ended in the Golconda. The other divergent line started with *P. abruptus* in the Golconda, evolved into *P. acutus* Wetherby and *P. bifurcatus* Wetherby in the Glen Dean and became extinct at the end of the Glen Dean.

The most probable relationships of the species erected chiefly on the characters of the appendages or "wing plates" are shown in the accompanying diagram (fig. 3). In this diagram the names of species which are considered as most prob-

[3] Idem, p. 46.

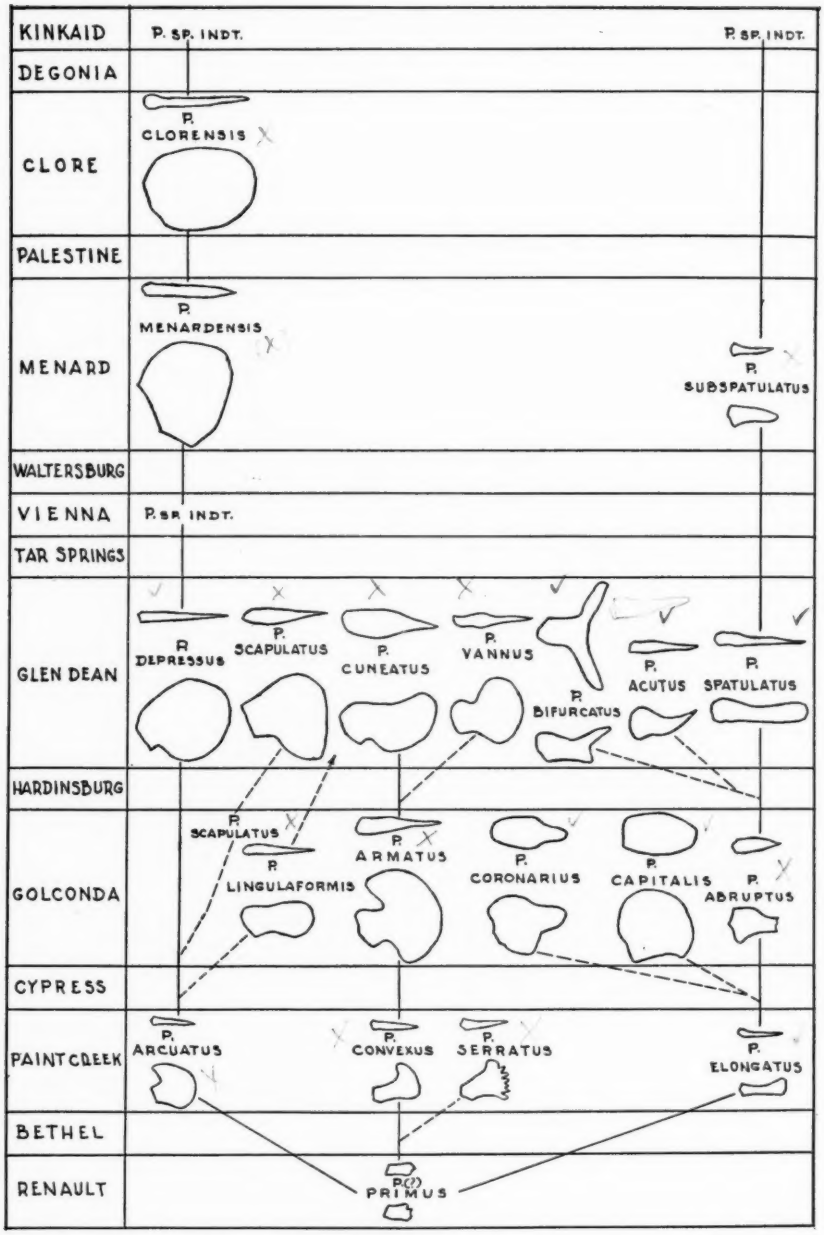

FIG. 3 DIAGRAM SHOWING RELATIONSHIPS OF PTEROTOCRINUS SPECIES

ably in the main lines of development are connected by solid lines and those which are considered as offshoots or side branches are connected by dashed lines. The various names and sketches in the diagram in the spaces for the different formations are not placed in positions indicating their *immediate* stratigraphic occurrences, since in most formations the various species have all been found at the same approximate horizons, but are arranged in order to show them in the rather limited spaces. Each species is illustrated in the diagram by sketches showing a lateral view of the "wing plate" or appendage and a view from above, the plates being oriented in the positions they occupied on the right side of the calyx. All drawings one-half size. Several species defined on the basis of the plates of the calyx, the appendages being unknown, are described in this paper, but not included in the chart.

STRATIGRAPHIC VALUE

Not all of the species given in the diagram are good markers for the horizons in which they occur. This is not because the species are not restricted to the various formations but because of the scarcity of many of the forms. *P.* (?) *primus*, because of its rarity, is of no value as a marker in the Renault. Of the four species known from the Paint Creek, only *P. serratus* has proved to be widespread and abundant enough to be of much practical value. *P. elongatus* and *P. convexus* are good where present but are found much less often than *P. serratus*. *P. arcuatus* is of no especial significance for stratigraphic purposes.

Of all the species known from the Golconda, *P. capitalis* is the most widespread and of greatest value. It is known and used as a guide not only in the Eastern Interior Basin but in the southern portion of the Appalachian province as well. *P. armatus* is abundant locally as is also *P. lingulaformis* Sutton, n.sp. The other species are more restricted in their occurrence and consequently of less value. Several species from the Glen Dean are of considerable value, the most widespread and most important being *P. depressus*, which occurs throughout the basin. *P. acutus* is somewhat less extensive in its occurrence, but is of special value along the northeastern portion of the western Kentucky coal field. The others are good where found but are known from fewer localities.

No species are known from the Vienna, the only representative of the genus being fragments of plates similar to those of members of the *P. depressus* gens. *P. menardensis* Weller is the most widespread species of the Menard formation and constitutes a good guide over a considerable area in southern Illinois and western Kentucky. *P. clorensis* Sutton, n.sp., of the Clore formation is distinctive but very rare. The large "wing plates" which occur in the Kinkaid are diagnostic, but as far as known are limited to an area in the Smithland and Golconda quadrangles in western Kentucky. No specimens of these plates have been found which are complete enough to warrant specific description. Other forms in the upper Chester are too scattered in their occurrence to be of much value.

DESCRIPTION OF SPECIES

In erecting species within this genus several factors have been taken into account. Because of the rapid evolution, many intergrading forms occur. Young individuals are often somewhat different in general appearance than more mature specimens. In general, stratigraphic occurrence has been given high rating in defining species, and similar forms which occur together have been placed in the same species, although if found in different horizons they might have been placed in different species. It is often difficult to strike a happy medium be-

tween splitting fossils of this type into too many species and grouping them into too few, either method impairing their value as guides. The writer has endeavored to keep in mind that the primary value of fossil species is to serve as horizon markers and has defined the species with this idea in view. If there has been a tendency to err he hopes that it has been toward too fine dividing since this is the lesser of two evils as far as the stratigraphic value of the forms is concerned.

PTEROTOCRINUS (?) PRIMUS Sutton, n. sp.
Plate 49, figures 5–6

Only one incomplete appendage of this species is known, the base and part of the petiole being missing. The petiole portion of the appendage is somewhat thicker vertically than transversely and the plate expands distally in both directions forming a somewhat club-shaped end which has several small pointed tubercular extensions. Dimensions of the type are: transverse thickness of the petiole 2.95 mm., vertical thickness of petiole 3.8 mm., greatest thickness of distal portion 4.93 mm.

The writer realizes the inadvisability of erecting a species upon such insufficient material, and under ordinary circumstances would not define a species on the basis of one incomplete specimen but because of its significance as the possible ancestral form from which the other later species evolved, he feels justified in naming it and placing it at least provisionally in the genus.

Renault limestone, Fairview Bluff, Hardin County, Illinois. Collected by Stuart Weller. Walker Museum. Holotype, 30210.

PTEROTOCRINUS DEPRESSUS GENS

PTEROTOCRINUS ARCUATUS Sutton, n. sp.
Plate 49, figures 1–2

WELLER, *1920*, Ill. Geol. Survey, Bull. 41, pl. 5, fig. 28. Figured but not named or described.

This species is based on the "wing plate" only, which has a pronounced arcuate blade portion. The margin of the plate, like all other species of this gens, is compressed to a knife-like edge except along the inner part near the area of attachment. The petiole is short, almost absent on the inferior edge but longer on the upper side, being about three-thirteenths of the length of the plate. The presence of a petiole is a primitive character of the gens but the notable shortening of it on the lower edge is a step in the general direction toward its absence in later members. The plate is thickest at the base, becoming slightly compressed immediately beyond the area of attachment. Above the compression it expands somewhat in transverse direction, being thickest about one-fourth of the length of the plate from the proximal end. From the area of greatest thickness it thins regularly toward the distal margin. Dimensions of type are: length of plate 12.75 mm., greatest width distally 15 mm., thickness of base 2.45 mm., greatest thickness of blade 1.95 mm.

This is the rarest of the Paint Creek species and is of no essential value as a stratigraphic marker. It is interesting because it shows the trend of development from the petiole stage of the early forms to those with only a very short petiole or none at all in later members of the *P. depressus* gens.

Paint Creek formation 6 miles south of Vienna, Illinois. Walker Museum collection. Holotype, 25384.

PTEROTOCRINUS LINGULAFORMIS Sutton, n. sp.
Plate 49, figures 25–28

Only the appendages of this species are known. They are linguloid in outline with but little vertical expansion in the blade portion, the distal part of which is compressed. The plates are compressed slightly both vertically and laterally just beyond the base. Beyond the compressed zone the expansion in a vertical direction is about equal both upward and downward so that the width of the blade is but little greater than the length of the area of attachment. The lateral expansion is such that the greatest thickness of

the blade is approximately equal to the thickness of the base. Average dimensions of five specimens are: length of plate 18.3 mm., greatest width 10.4 mm., greatest thickness 3.06 mm.

This species is much like *P. depressus* with respect to the constricted zone just beyond the base, but may easily be distinguished from it by the much narrower blade. It is considered as a divergent branch of the *P. depressus* line, no definite Golconda representative of the main line being known. *P. lingulaformis* is one of the two species of *Pterotocrinus* which are known to occur in two different formations.

Lower Okaw limestone in southwestern Illinois, Golconda limestone in southern Illinois and western Kentucky, and Glen Dean limestone in western Kentucky. Walker Museum collection. Cotypes, 37311; paratypes, 35155, lower Okaw limestone three-fourths of a mile north of Marigold, Illinois.

PTEROTOCRINUS SCAPULATUS Sutton, n. sp.
Plate 50, figures 17–19

Only the "wing plates" of this species are known. They are characterized by a pronounced downward flaring of the blade and only a very moderate upward expansion, resembling somewhat a human scapula in outline. The lower margin possesses a petiole about one-sixth of the length of the plate but this feature is absent or present in only a minor degree on the upper edge which is rounded. The greatest thickness occurs about midway of the short petiole portion, beyond which point the plate contracts to a knife-like margin. The plate is proportionally thicker than *P. depressus*, which it most resembles. Dimensions of a nearly complete specimen are: greatest length 19.4 mm., greatest width 16.5 mm., greatest thickness 5 mm.

This species, another Golconda offshoot of the main line of the *P. depressus* gens, may be recognized by the prominent downward expansion of the blade beyond the short petiole, a feature more pronounced in relation to the upward expansion in this species than in any other known form. The relatively greater thickness is also an aid in identification.

Lower Okaw limestone in southwestern Illinois and Glen Dean limestone in Pope and Randolph counties, Illinois. It is more abundant in the Glen Dean. Walker Museum collection. Cotype, 37308, Okaw limestone, three-fourths of a mile north of Marigold, Illinois. Cotype, 9391, Glen Dean limestone, Pope County, Illinois. Paratype, 26713, Glen Dean limestone, Menard, Illinois.

PTEROTOCRINUS DEPRESSUS Lyon and Casseday
Plate 49, figures 7, 8, 40–44

Pterotocrinus depressus LYON and CASSEDAY, *1860*, Am. Jour. Sci., 2d ser., vol. 29, p. 68. —MEEK and WORTHEN, *1873*, Ill. Geol. Survey, vol. 5, p. 599, pl. 21, fig. 13.—WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 796, pl. 79, figs. 2*a–e*.—ULRICH, *1905*, U. S. Geol. Survey, Prof. Paper 36, p. 58, pl. 6, figs. 25–26.—BUTTS, *1918*, Ky. Geol. Survey, Miss. Form. W. Ky., p. 100, pl. 24, fig. 12. —SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 50, pl. 14, figs. 4–4*a*.

The calyx as well as the "wing plates" of this species is known. Calyx slightly higher than wide with the dorsal cup shorter than the tegmen. Dorsal cup depressed and bowl-shaped with straight or slightly convex sides and with the lower part rounded. Plates smooth with rather indistinct sutures. The basal plates project slightly and possess a shallow concavity which is filled by the column. Radials irregularly pentagonal, expanding rapidly upward, with the distal faces excavated at both ends for the reception of the two outer tertibrachs of the proximal row. The middle portion is excavated to receive the primibrach and secundibrachs. The anal plate, in a notch formed by the basals, is irregularly hexagonal or quadrangular; if the former, the lower part is between the radials and the upper between two tertibrachs, if quadrangular, the two posterior radials

meet over the apex. Primibrachs small and trigonal, secundibrachs and tertibrachs larger and polygonal. Each series of tertibrachs consists of three fixed plates, usually quadrangular, although the outer plates of the proximal row are pentagonal or hexagonal. Arms short and biserial beyond the fourth or fifth tertibrach. Pinnules strong and close together.

Tegmen conical and higher than the dorsal cup. In general the plates are arranged like those of other species except the posterior oral which is pushed to the

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EXPLANATION OF PLATE 49

All natural size. All views of appendages or "wing plates" oriented with the base down and the upper or ventral edge of the plate to the left. In the crinoid they were oriented with the base at an angle against the sloping sides of the pyramidal tegmen.

FIGS. 1, 2—*Pterotocrinus arcuatus* Sutton, n.sp. Lateral and ventral views of the "wing plate," holotype, W. M., 25384.

3, 4—*Pterotocrinus pentalobus* Sutton, n.sp. Basal and right antero-lateral views of the calyx of the holotype, W. M., 19130.

5, 6—*Pterotocrinus* (?) *primus* Sutton, n.sp. Ventral and lateral views of the holotype, W. M., 30210.

7, 8, 40–44—*Pterotocrinus depressus* Lyon and Casseday. 7, 8, Ventral and lateral views of a good specimen, W. M., 37310. 40–42, Dorsal, lateral, and ventral views of three specimens. 43, 44, Ventral and lateral views of two "wing plates." (40, 41, and 44 after Wachsmuth and Springer, North American Crinoidea Camerata, pl. 79, figs. 2*b* and 2*c*.)

9, 10—*Pterotocrinus vannus* Sutton, n.sp. Lateral and ventral views of the holotype, W. M., 26713.

11–14—*Pterotocrinus cuneatus* Sutton, n.sp. 11, 12, 14, Lateral, ventral, and basal views of a nearly complete cotype, W. M., 37307. 14 shows the wedge-shaped cross section of the petiole. 13, Lateral view of a smaller cotype, W. M., 37306.

15–18—*Pterotocrinus elongatus* Sutton, n.sp. 15, 16, Dorsal (basal) and ventral views of the holotype, W. M., 26925. Basal view with posterior side down. 17, 18, Lateral and ventral views of paratype, W. M., 26864, a somewhat larger appendage.

19, 20—*Pterotocrinus pyramidalis* Lyon and Casseday. Lateral and basal views of the type. (After Springer, U. S. Nat. Mus., Proc., vol. 67, art. 9, pl. 13, figs. 21–22.)

21, 22—*Pterotocrinus rugosus* Lyon and Casseday. 21, Type specimen. (After Springer, U. S. Nat. Mus., Proc., vol. 67, art. 9, pl. 13, fig. 17.) 22, Basal view of a fairly good specimen, plesiotype, W. M., 19144.

23, 24—*Pterotocrinus chesterensis* Meek and Worthen. Posterior and lateral views of two type specimens. (After Wachsmuth and Springer, North American Crinoidea Camerata, pl. 79, figs. 5*b*–5*a*.)

25–28—*Pterotocrinus lingulaformis* Sutton, n.sp. 25–27, Lateral views of three specimens showing variation in outline. 25 and 26 cotypes, W. M., 37311. 27, A variety in which serrations are well developed, W. M., 25155. 28, Ventral view of 26.

29–31—*Pterotocrinus abruptus* Sutton, n.sp. 29, 31, Lateral and ventral views of the holotype, W. M., 37303. 30, Lateral view of a paratype, W. M., 37304.

32, 33—*Pterotocrinus convexus* Sutton, n.sp. Lateral and ventral views of the holotype, W. M., 37312.

34–39—*Pterotocrinus armatus* Sutton, n.sp. 34, 35, and 39, Ventral, lateral, and basal views of the holotype, W. M., 34906A. 36–38, Lateral views of paratypes, W. M., 34906, illustrating variations in size and shape at different ages.

45, 46—*Pterotocrinus subspatulatus* Sutton, n.sp. Lateral and ventral views of the holotype, W. M., 30861A.

47–49—*Pterotocrinus menardensis* Weller. 47 and 48, Lateral and ventral views of the holotype, W. M., 25425. 49, View of a detached basal plate, plesiotype, W. M., 30827.

50, 51—*Pterotocrinus serratus* Weller. Lateral and ventral views of a good specimen, plesiotype, W. M., 25577.

52, 53—*Pterotocrinus clorensis* Sutton, n.sp. Ventral and lateral views of the holotype, U. of I., M385, an incomplete plate.

Sutton, Mississippian crinoids

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anterior side by the anus instead of being simply wedged between the other four. The anal opening is at the top of a small cone or tube in the center of the ventral disk. The interradial spaces are longitudinally grooved. Four of the sides are composed each of three interambulacral plates followed by the oral plate. The posterior space is composed of many small plates round the anal tube.

The appendages are thin and leaf-like, almost flat on the lateral faces and thickest at the base from which point they thin to knife-like distal edges. In some specimens there are small constrictions both vertically and laterally just beyond the base but not as conspicuous as in *P. lingulaformis*. The appendages project out as five large blades far beyond the limits of the arms. The interradial and other dome plates are small. Average measurements of three specimens are: length of plate 16.8 mm., greatest width distally 18.6 mm., thickness 2.68 mm.

The appendages of this species differ from similar forms in the Golconda by a marked expansion of the blade both upward and downward from the area of attachment although in some specimens the downward expansion is more pronounced than the upward. They are relatively thinner than similar forms in higher horizons.

Upper part of the lower Okaw limestone in southwestern Illinois, Glen Dean formation around the Eastern Interior coal field in southern Illinois and Kentucky and in Pulaski County, Kentucky. Lyon collection.

PTEROTOCRINUS MENARDENSIS Weller
Plate 49, figures 47–49

Pterotocrinus menardensis WELLER, *1920*, Ill. Geol. Survey, Bull. 41, p. 373, pl. 11, fig. 9.

"Wing plates" and detached basal and radial plates of this species are known. The basals are large, heavy, and irregularly pentagonal with a pronounced concavity larger than the column. The radials are subquadrangular, less expanded upward than in most species, straight or slightly concave along the upper edge. The appendages are large, thin, and subovate in outline, with the margin compressed to a knife-like edge except where the plate is attached. The upper margin of the plate is arcuate and the lower margin somewhat pointed. The plate is compressed slightly in a lateral direction immediately above the base but expands vertically from the attached area or has only a minor constriction on the lower edge. The compression into the thin knife-like edge begins relatively close to the margin, unlike the older species of this gens in which the compression begins near the center of the mid-length. Dimensions of the holotype are: greatest length horizontally 24.3 mm., greatest width distally 28.2 mm., length of base 14.2 mm., greatest thickness 3 mm.

The "wing plates" of this species resemble most those of *P. depressus* in their thinness and expansion. The plates of *P. menardensis* are larger and have a less pronounced constriction near the base and the compression to the thin margin begins much farther toward the edge than in *P. depressus*.

Menard limestone in southern Illinois and as far east as eastern Christian County, Kentucky. Walker Museum collection. Holotype, 25424, Menard limestone, 2 miles east of Cobden, Illinois. Plesiotype, 30827, lower Menard limestone, Walche's Cut, east of Scottsburg, Kentucky.

PTEROTOCRINUS CLORENSIS Sutton, n. sp
Plate 49, figures 52, 53

This species is erected on the basis of the "wing plate" only. The plates resemble those of *P. menardensis*, which is undoubtedly the direct ancestral form. The plate contracts rather pronouncedly in a lateral direction immediately beyond the base. Beyond the contraction it expands to the thickest part near the center of the plate and beyond that point contracts rather uniformly to a knife-like margin. The plate is large and broadly ovate in outline, with the verti-

cal expansion about equal from both ends of the base. Dimensions of the holotype are: length 30 mm., width 25 mm., greatest thickness 3.65 mm.

This species resembles in some respects *P. menardensis* but may be distinguished from it in the proportionally greater length horizontally, the somewhat less pointed lower margin, and the fact that the greatest thickness of the blade portion is near the mid-length, from which point the plate thins to the margin, whereas in *P. menardensis* the diminishing of the thickness begins near the margin.

Clore limestone in Livingston County, Kentucky. Fragments of the plates are not uncommon but only rarely are the complete plates found. It is probable that the species is more widely distributed than in the restricted area noted. University of Illinois collection. Holotype, M 385. One and one-half miles south of Smithland, Kentucky.

PTEROTOCRINUS sp. indt.

Large "wing plates" similar to those of *P. clorensis* and *P. menardensis* have been found in the Kinkaid limestone at a number of localities in the Golconda and Smithland quadrangles in western Kentucky, but none complete enough to attempt a specific definition are available. These plates are considerably thinner proportionally than either of the other two species. This form is mentioned here because it shows the continuation of the *P. depressus* line of development to the end of the Mississippian period, and because the forms even if not named constitute a help in stratigraphic identification. No doubt further search may bring to light specimens good enough to warrant specific description.

PTEROTOCRINUS ARMATUS GENS

PTEROTOCRINUS CONVEXUS Sutton, n. sp.
Plate 49, figures 32, 33

WELLER, *1920*, Ill. Geol. Survey, Bull. 41, pl. 5, fig. 27. Figured but not named or described.

Only the "wing plates" of this species are known. They are subspatulate in form with the lateral margins subparallel for more than half the length of the plate, the petiole portion. Beyond this point they become more widely divergent distally. The sides of the plate are unevenly concave in outline through the petiole portion, the greater concavity being along the upper edge, a feature which becomes more pronounced in some of the later species of this gens. The plate is slightly constricted both vertically and laterally just beyond the base. The distal margin is regularly convex and compressed to a knife-like edge. Dimensions of the holotype are: greatest length 13.1 mm., greatest width of blade 10.1 mm., greatest thickness which is at the base, 2.55 mm.

This species is the first of a line which develops into much more massive and heavy plates in succeeding formations. The higher forms also develop a petiole much more curved than characterizes this species.

Paint Creek formation throughout the Illinois and Kentucky portions of the Eastern Interior Basin. Walker Museum collection. Holotype, 37312, 6 miles south of Vienna, Illinois.

PTEROTOCRINUS SERRATUS Weller
Plate 49, figures 50, 51

Pterotocrinus serratus WELLER, *1920*, Ill. Geol. Survey, Bull. 41, p. 342, pl. 5, figs. 24–26.

Weller's original description, which can hardly be improved, is as follows:

This species is based on the "wing plates" only which are subspatulate in form. The lateral margins are subparallel proximally but become more or less widely divergent distally, being unevenly concave in outline. The distal margin is more or less arcuate or nearly straight, the plates becoming very thin distally and being divided by incisions of varying depth into a series of serrations. Dimensions of the holotype are: length of plate 11.2 mm., greatest width distally 7.7 mm. Another specimen with a length of about 12.5 mm. has a maximum width of about 11.5 mm.

In general outline this species is much the same as *P. convexus*, the only essential difference between the two being the serrations in the distal portion of the blade of *P. serratus*. Examination of a great number of the thin expanded blades of both this gens and the *P. depressus* gens shows that the development of serrations occurs in many specimens which are otherwise the same as typical specimens of a species. This is particularly true of *P. armatus*. The writer's conclusion is that the serrations are the result of growth stages of the plates during the life of an individual and are not of specific value. This feature is developed to a much greater extent in the Paint Creek forms than in later species as might be expected among older more primitive species of the genus. Because of the much more common occurrence of specimens showing serrations in the Paint Creek, which makes it a reliable guide for the formation, *P. serratus* is considered as being worthy of ranking as a valid species although the serrated character is not considered as of specific value in later horizons.

Paint Creek formation throughout Illinois and western Kentucky. Walker Museum collection. Holotype, 25377; paratype, 25376; plesiotype, 25577.

PTEROTOCRINUS ARMATUS Sutton, n. sp.
Plate 49, figures 34–39

This species is erected on the "wing plates" only which are widely divergent in the blade portion and possess a thick petiole, the sides of which are pronouncedly concave in outline. The upper portion of the blade expands outward and upward making an angle of less than 90° between the blade and petiole. The petiole is massive, thicker on the upper edge than the lower, almost flat on the upper surface, and about equal in vertical width to the length of the area of attachment. The plate increases in thickness from the base to the thickest portion near the distal end of the petiole. The plate is narrowest vertically through the petiole at the point where the rapid expansion of the blade begins. The blade decreases uniformly in thickness from the place of its union with the petiole to the margin which is thin and knife-like. Dimensions of the holotype, which is exceptionally large, are: greatest length horizontally 25 mm., greatest width of blade 24.5 mm., greatest thickness 5 mm.

Probably a greater diversity of form has been included in this species than in any other. Much of the difference in shape is due to the age of the individual. However, they all possess the essential features given above. Many specimens, especially smaller ones, display the tendency toward serrations in the distal part of the blade but not to the extent as in *P. serratus*. This species undoubtedly is the lineal descendant of *P. convexus* of the Paint Creek with modifications which are least apparent in small specimens and attain a maximum in the larger, older ones.

Golconda limestone in western Kentucky. Walker Museum collection. Holotype, 34906A; paratypes, 34906, one-half mile north of Forest Grove School, Marion, Kentucky.

PTEROTOCRINUS CUNEATUS Sutton, n. sp.
Plate 49, figures 11–14

Calyx unknown. "Wing plates" heavy, especially in the basal and petiole portions. Vertical cross section through the petiole pronouncedly wedge-shaped with rounded upper side. The plate is slightly constricted just beyond the base and then thickens rapidly, becoming thickest about half-way between the base and the beginning of the expansion of the blade. The blade contracts rapidly to a knife-like margin. The upper margin of the plate is convex in outline through the petiole portion and concave through the blade. The plate is vertically constricted in the petiole on the lower margin, the constriction being followed by an expansion. Distal margin more or less regularly convex. None of the specimens have

the blade portion completely preserved so the following measurements are only approximate. Average dimensions of four specimens are: length 26.5 mm., width of blade 19 mm., greatest thickness 7.27 mm.

This species represents the last of the main line of the *P. armatus* gens and like the other Glen Dean species of this and the *P. spatulatus* gens is characterized by the massiveness of the plate. It resembles most *P. armatus* of the Golconda in its massiveness. The blade, however, is much less expanded upward and the petiole is much thicker and more rounded on the upper side than in *P. armatus*, which possesses a flat upper surface on the petiole.

Glen Dean limestone in southwestern and southern Illinois. No specimens are known to the writer from the Kentucky exposures of the formation. Several specimens of this species in the Gurley collection at Walker Museum are labelled as from the Kaskaskia, but the other forms contained in this collection appear to the writer to be undoubted Glen Dean species. Walker Museum collection. Cotypes, 37306, Glen Dean limestone, Menard, Illinois, and 37307, Kaskaskia (Glen Dean) limestone, Pope County, Illinois.

PTEROTOCRINUS VANNUS Sutton, n. sp.
Plate 49, figures 9, 10

Only one nearly complete appendage of this species is known. The plate is fan-shaped, the expansion of the blade being nearly equal both upward and downward from the petiole. It is somewhat constricted both vertically and laterally beyond the base, the vertical constriction being greatest at the distal extremity of the petiole and the lateral constriction greatest immediately beyond the base. The general shape of the petiole is somewhat like that of *P. cuneatus* except the rounding on the upper edge is less pronounced and the relative thickness less. The plate is constricted to a knife-like edge along the distal margin. Dimensions of the holotype are: length 20.1 mm., width of blade 18 mm., greatest thickness 4.93 mm., greatest height of petiole 8.8 mm.

This species is readily distinguishable by the fan-like outline, a feature in which it differs from other species of the *P. armatus* gens. It is considered as an offshoot of the main line and is not a reliable guide because of its scarcity.

Glen Dean limestone, Menard, Illinois. Walker Museum collection. Holotype, 26713.

PTEROTOCRINUS SPATULATUS GENS

PTEROTOCRINUS ELONGATUS Sutton, n. sp.
Plate 49, figures 15–18

Calyx small, a little wider than high. Dorsal cup bowl-shaped with sides slightly convex and deflected outward at the secundibrachs. Plates smooth, sutures rather indistinct. Anal plate large, pentagonal, as high as the radials with the distal end deflected inward. Other plates in the dorsal cup typical of the genus except the radials which are only slightly excavated in the central part of the upper edge. Column round and completely filling the columnar cavity. Tegmen crushed in the type specimen. Primibrachs subquadrangular, secundibrachs quadrangular and heavier than the lower quadrangular tertibrachs. Arms twenty, biserial above the fourth or fifth tertibrach. Appendages long, flat, and narrow with only a slight upward expansion in the distal portion, thickest at the base and contracting more or less regularly to the knife-like distal end. Dimensions of one perfect specimen somewhat larger than the holotype are: length 13.7 mm., thickness of base 2.23 mm., width of extended distal portion 4.15 mm., length of base 3.83 mm.

This species represents the beginning of the *P. spatulatus* gens, the species of which possess relatively narrow, elongate appendages, except two species, *P. capitalis* and *P. coronarius* which have been included for reasons stated elsewhere. This line of evolution continued until the end of the Chester epoch. The

most distinguishing features of this species are the elongate appendages and the relatively large size of the anal plate.

Paint Creek limestone in many localities in Illinois and Kentucky. Walker Museum collection. Holotype and paratype 26925, 1¼ miles northwest of Floraville, Illinois. Other paratypes 26864, 2 miles south of Columbia, Illinois.

PTEROTOCRINUS ABRUPTUS Sutton, n. sp.
Plate 49, figures 29–31

Calyx unknown. Appendages relatively heavy and short but possessing the characteristic feature of the gens, no petiole and a narrow shape. The appendages are widest at the base and thickest about one-third of the length from the proximal end. They are thicker above than below and somewhat rounded on the upper edge. The plate contracts rapidly and terminates in a narrow, blunt, blade-like end. Dimensions of the holotype are: length 13.2 mm., length of base 9.27 mm., greatest thickness 4.4 mm., vertical width of distal end 4 mm.

This species undoubtedly is the forerunner of *P. spatulatus*, *P. acutus*, and *P. bifurcatus* of the Glen Dean. The shape of the proximal portion is more like *P. acutus* while the distal portion of the blade is more like *P. spatulatus*. Since the latter feature is continued among species in the higher formations, *P. spatulatus* is placed in the direct line of development and the other species considered as divergent branches. All of these forms are characterized by a heavy proximal portion as are almost all Golconda and Glen Dean forms of this gens, as well as the *P. armatus* gens.

Golconda limestone in western Kentucky. Walker Museum collection. Holotype and paratypes 37307, 8 miles southeast of Scottsburg, Kentucky. Other paratypes No. 37304, 1¼ miles southwest of Claxton, Kentucky.

PTEROTOCRINUS CAPITALIS (Lyon)
Plate 50, figures 20–24

Asterocrinus capitalis LYON, *1875*, Geol. Rept. Ky., vol. 3, p. 472, pl. 3, figs. 1–1*k*.

Pterotocrinus capitalis WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 794, pl. 79, figs. 6*a–b*. —ULRICH, *1905*, U. S. Geol. Survey, Prof. Paper 36, p. 58, pl. 6, figs. 21–22.—BUTTS, *1918*, Ky. Geol. Survey, Miss. Form. W. Ky., p. 95, pl. 23, figs. 1–4.—WELLER, *1920*, Ill. Geol. Survey, Bull. 41, p. 360, pl. 8, figs. 36–39.—SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 49, pl. 13, figs. 23.

Crown viewed from above irregularly star-shaped. Dorsal cup about as wide as high and composed of heavy unornamented plates. Number and arrangement of the plates typical of the genus. The arms are biserial beyond the second tertibrach unlike most members of the genus which have four or five rows of single tertibrachs in the lower part of the arms. The appendages are large and massive, thinnest at the base and expanding more or less uniformly to the upper and outer margins, often being more than twice as thick at the outer portion than at the base. They vary from flat to gently convex on the upper side and are usually gently concave in outline along the under side. Dimensions of a typical plate are: thickness at base 6 mm., thickness at upper margin 12.15 mm., length of attached area 15 mm., horizontal length of plate 18.9 mm., width of distal portion 20.4 mm.

This species is the genotype of *Pterotocrinus* and is characterized by the massiveness of the appendages, which are approached in this respect only by those of *P. coronarius* to which species it is very closely related. The position of these two species in the general scheme of classification has been the most difficult of all to determine. They certainly do not belong in any of the main lines of development of any of the three gentes defined. They are most like the other Golconda and Glen Dean members of the *P. spatulatus* gens in the rapid expansion of the plate from the base and in the absence of a petiole portion. However, they differ from other species of the gens in the absence of more than a rudimentary extended distal portion of the plate. It is

possible that they might be a direct line of development from the primitive form of *Pterotocrinus*, but if this is the case no connecting forms have been found in the Paint Creek formation. In spite of the differences between them and the typical members of the gens, the similarities have been considered important enough to warrant the inclusion of them as a divergent line of development of the *P. spatulatus* gens, the divergence having occurred some time during Cypress time in an area removed from the Eastern Interior Basin. This is considered as the time of divergence because these two species occur commonly in the lower part of the Golconda and lower Okaw formations.

Lower part of the lower Okaw formation in southwestern Illinois and of the Golconda limestone in southern Illinois and western Kentucky as far east as Christian County, and also in Alabama. The absence of it from the Golconda east of Christian County along the western Kentucky coal basin may be due to the absence of the lower portion of the Golconda formation as developed farther west or to conditions unfavorable to its presence in this area during Golconda time. Holotype in Lyon collection. Plesiotypes, Walker Museum, 30247A. Plastoholotype, Walker Museum, 15850.

PTEROTOCRINUS CORONARIUS (Lyon)
Plate 50, figures 25–31

Asterocrinus (?) *coronarius* LYON, *1857*, Geol. Rept. Ky., vol. 3, p. 467, pl. 1, figs. 1–1*a*.
Pterotocrinus coronarius WACHSMUTH and SPRINGER, *1897*, North American Crinoidea, p. 795, pl. 79, figs. 7*a–b*.
Pterotocrinus cirnarius WILSON, *1926*, Jour. Geology, vol. 24, p. 510, pl. 3, fig. 11.
Pterotocrinus coronarius SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 48, pl. 14, figs. 1–3*a*.

Calyx large. Basals small and flat, radials very large, larger than all the other plates of the cup combined, forming large gibbous protuberances which constitute the greater portion of the cup. Anal plate small. The single primibrachs and secundibrachs are relatively large. The appendages are like those of *P. capitalis* in size and massiveness but are distinguished from those of the latter species by the pronounced concave upper surface of the plate and the development of a distal protuberance from the upper margin. This protuberance exhibits considerable variation in shape, in some specimens being a mamillary-like mound, in others a pronounced cone, and in still others somewhat blade-like in shape. The concavity of the upper surface is likewise variable, ranging from a shallow depressed central portion to a pronounced depression with widely flaring bounding sides.

The structure of this species is an anomaly. The exceedingly large size and protuberant shape of the radials is in striking contrast to most other species of the genus which are characterized by relatively small radials with cylindrical exteriors. The central part of the tegmen is concave instead of convex as is true for the other species. In spite of the differences noted above, *P. coronarius* is undoubtedly more closely related to *P. capitalis* than to any other species of the genus and is included with it in the same divergent line of development. A species described by Hall in 1858 as *Dichocrinus protuberance* is probably identical with this species.[4]

This species has been reported from two localities in the Golconda limestone, near Vienna in southern Illinois and from Crittenden County, Kentucky, and from the lower Okaw limestone near Marigold in southwestern Illinois. The plates are so distinctive that wherever they are found they constitute an excellent index for the Golconda and lower part of the lower Okaw. Holotype in the Lyon collection. Plesiotypes Walker Museum, 30535.

PTEROTOCRINUS SPATULATUS Wetherby
Plate 50, figures 5–8

Pterotocrinus spatulatus WETHERBY, *1879*, Cincinnati Soc. Nat. Hist., Jour., vol. 2, p. 137, pl. 2, fig. 3*a–c*.

[4] Hall, James, Geol. Rept. Iowa, pt. 2, p. 689, pl. 25, fig. 7.

Dorsal cup small and shallow. Basals pentagonal with the interradial angles most pronounced. Anal plate small with the radials meeting above its upper angle. Radials large, rapidly expanding upward and concave on the upper side. The concavity of the superior edge of each radial is least in the center where the upper margin is slightly extended. Primibrachs small, sometimes hidden from external view by the secundibrachs which are slightly larger than the tertibrachs. Arms short, tapering and biserial beyond the fourth plate. Ventral disk pyramidal and a little wider than high. The interambulacral spaces are triangular and covered with longitudinal grooves in which the arms rest. The four regular sides each contain four plates, three interambulacrals and one oral, the two upper interambulacrals and the oral being beveled at one side to form the socket for the appendages. The anal interray is wider than the others and composed of many plates. The posterior oral is excavated on one side by the anal opening. The upper ends of the four other orals bend in and form a small platform.

The appendages are long and slender, thicker above than below and spatulate in form. In outline they are concave above and straight or slightly convex along the lower side. They are constricted laterally just beyond the base and expand to the greatest thickness beyond this constriction. From the point of maximum thickness they contract more or less uniformly to a thin spatulate distal portion. They are narrowest vertically about midway of the length. Normally the proximal portion is slightly wider vertically than the distal end. Dimensions of a nearly perfect appendage are: length 26.1 mm., vertical width near the base 6.7 mm., greatest width of distal portion 5.5 mm., narrowest vertical portion of the plate 4.5 mm., greatest thickness 3.5 mm.

Wachsmuth and Springer have considered this species as identical with *P. acutus* but the writer feels that the differences in the appendages of the two are distinct enough to warrant specific differentiation. The appendages of *P. acutus* are awl-shaped at the distal end and much more curved than those of *P. spatulatus*, which are spatulate at the distal extremity. Wachsmuth and Springer also considered *P. rugosus* as probably identical with *P. acutus*, but as will be shown in the discussion of *P. rugosus* it is a distinct species much more closely related to *P. depressus* than to *P. acutus*.

This species has not been reported from the border of the Eastern Interior coal field but has been found rather abundantly in the Glen Dean formation in Pulaski County, Kentucky. Walker Museum collection. Holotype, 6402.

PTEROTOCRINUS ACUTUS Wetherby

Plate 50, figures 10–13

Pterotocrinus acutus WETHERBY, *1879*, Cincinnati Soc. Nat. Hist., Jour., vol. 2, p. 134, pl. 11, fig. 2.—WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 799, pl. 79, figs. 3*a–g*.—ULRICH, *1905*, U. S. Geol. Survey, Prof. Paper 36, p. 58, pl. 6, figs. 23–24.—WOOD, *1909*, U. S. Nat. Mus., Bull. 64, p. 43.—BUTTS, *1918*, Ky. Geol. Survey, Miss. Form. W. Ky., p. 100, pl. 24, figs. 15–16.—SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 50, pl. 13, figs. 16.

General arrangement and character of plates in the calyx the same as in *P. spatulatus*. The appendages are long and generally curved upward terminating in a point. They are thicker on top than below as a rule, the greatest thickness being from one-third to one-half the distance from the base. The different specimens exhibit considerable variations in the degree of upward bending of the distal portion of the plate. Dimensions of an average size appendage are: horizontal extent 20 mm., length of base 9.1 mm., greatest thickness 4 mm.

This species is undoubtedly most closely related to *P. spatulatus*, from which it differs essentially only in the character of the appendages. It is considered as a divergent evolution from *P. spatulatus*, which is the Glen Dean representative of the main line of development of the *P. spatulatus* gens.

This form is widespread in the Glen Dean formation in the Eastern Interior Basin and farther east in Kentucky and in the upper part of the lower Okaw in southwestern Illinois. It is more common than *P. spatulatus* and constitutes one of the more reliable Glen Dean guides. Walker Museum collection. Holotype, 6403; plesiotypes, 26711.

PTEROTOCRINUS BIFURCATUS Wetherby
Plate 50, figures 14–16

Pterotocrinus bifurcatus WETHERBY, *1879*, Cincinnati Soc. Nat. Hist., Jour., vol. 2, p. 136, pl. 11, fig. 1.
Pterotocrinus acutus var. *bifurcatus* WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 801, pl. 79, figs. 9*a–b*.
Pterotocrinus bifurcatus BUTTS, *1918*, Ky. Geol. Survey, Miss. Form. W. Ky., p. 100, pl. 24, fig. 14.—WELLER, *1920*, Ill. Geol. Survey, Bull. 41, p. 372, pl. 10, fig. 14.—SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 50, pl. 14, fig. 5.

The general arrangement of plates in this species is like that in *P. acutus* and *P. spatulatus*. The dorsal cup is higher with proportionally deeper basals, which are excavated on the lower faces and sharply edged around the margin. Column small, filling about one-half the basal cavity. The appendages are large and heavy and divided distally into two widely divergent horn-like portions. This division of the appendage is a feature shown by only one other species, *P. coronarius*, of the Golconda. In the latter form, however, the bifurcation occurs on the upper part of the appendage and not in the distal portion. Considerable variation exists in the form of the appendage among specimens of *P. bifurcatus*, but the bifurcated character is always present in some degree of development. In some specimens the divisions from adjacent rays meet at the ends or even overlap. The appendages are much thicker on the superior edge than on the lower and commonly are thickest close to the point of bifurcation. They expand more or less uniformly from the base to the thickest portion with only a minor lateral constriction immediately beyond the area of attachment. Each prong of the process ends in a point.

This species is one of the most peculiar of this unique genus. It apparently is most closely related to *P. acutus* and *P. spatulatus* in regard to the shape of the appendage in the proximal portion before the bifurcations. It is certainly a divergent development from one of the above two, but the writer cannot say definitely which one. The general character of the appendage in the proximal portion is more like *P. acutus*.

Upper portion of the lower Okaw formation in Randolph County, Illinois, and Glen Dean formation in Breckenridge and Pulaski counties, Kentucky.[5] Walker Museum collection. Holotype, 5401.

PTEROTOCRINUS SUBSPATULATUS
Sutton, n. sp.
Plate 49, figures 45, 46

Only the appendages of this species are known. They are small and subspatulate in outline. The greatest thickness is at the base, beyond which the plate is constricted to about half the thickness of the base, a thickness which is maintained more or less uniformly to near the distal end where it contrasts to a knife-like margin. The plate decreases rather more gently in vertical width from the base to the end and is rounded on both upper and lower edges. As is true of all species of *Pterotocrinus*, different specimens display variations in shape. Dimensions of the holotype are: length 13.45 mm., length of area of attachment 6.3 mm., thickness of base 3.5 mm., average thickness throughout most of

[5] Since the preparation of this paper a few specimens of *P. bifurcatus*, associated with *P. capitalis* and *P. coronarius*, have been found in the Golconda formation at one locality in Johnson County, Illinois. These specimens are small and the bifurcations not especially prominent but they clearly are the ancestral forms from which the later ones evolved. This is the only known occurrence of the species except in the Glen Dean formation.

the length of the blade 2 mm., vertical width near the distal end 3.4 mm.

This species represents the continuation of the *P. spatulatus* gens in the Menard, no species of it being known from the Vienna. *P. subspatulatus* possesses one feature somewhat suggestive of *P. acutus*, the contraction in a vertical direction in the distal portion. However, it is more like *P. spatulatus* in the shape of the blade and relative thickness of the proximal part of the appendage.

This species has been reported from the Menard limestone in only one locality, 2½ miles north of Princeton, Kentucky. Walker Museum collection. Holotype, 30861A; paratypes, 30861.

PTEROTOCRINUS sp. indt.

Pterotocrinus appendages or "wing plates" which are very similar to those of *P. subspatulatus* and *P. spatulatus* have been noted in a number of localities in the Kinkaid limestone in western Kentucky. No specimens suitable for specific description have been secured but they are mentioned here because of their significance in showing the continuation of the *P. spatulatus* gens until the end of the Mississippian period.

MISCELLANEOUS SPECIES

The following described species of *Pterotocrinus* have been named from some features other than the character of the appendages. In all of these the appendages are either unknown or known only from such imperfectly preserved specimens that it is impossible to determine definitely their characters. Because of this fact it has not been possible to assign them to definite places in the evolutionary chart. Another difficulty in the study of some of them is that the early describers assigned them to the Kaskaskia group and not to any particular horizon of the Chester as we now classify the series. It is possible that some of these species may be synonymous with some of the forms which have been named on the basis of the appendages. However, they are included in this paper in order to make the discussion of the genus complete.

PTEROTOCRINUS PENTALOBUS Sutton, n. sp.
Plate 49, figures 3, 4

Only the calyx up to and including the secundibrachs known. Calyx small, bowl-shaped, and distinctly pentalobate in outline when viewed from the base. The lobate character is due to constrictions in the calyx at the upper ends of the interradial sutures. Plates relatively heavy with sutures somewhat depressed. Arrangement of plates typical of the genus. The anal plate is relatively large, pentagonal in outline, and higher than the radials, comparing in size with the anal plate of *P. elongatus*. Radials nearly twice as wide as high and about twice as wide along the upper edge as along the lower. They are excavated for about three-fourths of the length of the upper edge for the reception of the brachials. The outer unexcavated ends of the radials were not in contact with the proximal tertibrachs, an unusual feature in the genus, in most species of which the outer plates of the proximal row of tertibrachs extend much closer to the ends of the radials than they do in this species. Primibrachs small and triangular resting in the center of the excavated upper margins of the radials. Secundibrachs also small, pentagonal, axillary, and in contact with the primibrachs and radials. Tertibrachs unknown, but the junctions of them with other plates of the calyx are evident in the specimens. The two middle ones of the proximal row of each ray were in contact with the secundibrachs and the two outer ones with the secundibrachs and radials. Column small, round, occupying the entire columnar cavity.

This species is readily distinguishable by the pentalobate form of the calyx and by having a considerably larger portion of the upper edge of the radials not in contact with the brachials. It is most like *P. elongatus* in the size of the calyx and the large size of the anal plate. Its

position in the evolutionary classification is not determinable.

Chester series, Randolph County, Illinois. Gurley collection, Walker Museum, 19130.

Pterotocrinus chesterensis Meek and Worthen

Plate 49, figures 23, 24

Dichocrinus (Pterotocrinus) chesterensis Meek and Worthen, *1860*, Acad. Nat. Sci. Phil., Proc., p. 383.

Pterotocrinus chesterensis Meek and Worthen, *1866*, Ill. Geol. Survey, vol. 2, p. 292, pl. 23, figs. 1*a–c*.—Keyes, *1894*, Mo. Geol. Survey, vol. 4, p. 206.—Wachsmuth and Springer, *1897*, North American Crinoidea Camerata, p. 802, pl. 97, figs. 5*a–b*.

This is one of the smallest species of *Pterotocrinus*. Dorsal cup with rapidly expanding concave sides, base truncated with lower margins projecting, plates smooth with ungrooved suture lines. Radials nearly twice as wide as high and rapidly expanding upward. The outer portions of the radials are truncated and the central portion excavated. Anal plate subovoid, almost as wide as the radials proximally and angular above. Primibrachs small and triangular, secundibrachs irregularly pentagonal, fixed tertibrachs four in number, the two outer ones in line with the secundibrachs and resting on the radials. Arms biserial from the third plate, small and rounded on the outer side. Structure of the tegmen and appendages unknown.

Although the only specimen of this species known to the writer is listed as from the Kaskaskia or Chester, its small size and general character suggest that it is most probably a lower Chester species.

Chester series in southern and southwestern Illinois. (Worthen) Illinois State collection, Springfield.

Explanation of Plate 50

All natural size

Figs. 1–4—*Pterotocrinus wetherbyi* Miller and Gurley. 1, Lateral view showing the furrowed tegmen. 2–4, Lateral, ventral, and dorsal views of the three cotypes, W. M., 6417. (After Miller and Gurley, Ill. State Mus., Bull. 6, pl. 4, figs. 6–9.)

5–8—*Pterotocrinus spatulatus* Wetherby. 5–6, Ventral and dorsal views of a somewhat crushed specimen; 5, oriented with the posterior side to the lower right and 6 turned slightly to the left. 7–8, Ventral and lateral views of a nearly perfect appendage, holotype, W. M., 6402.

9—*Pterotocrinus crassus* Meek and Worthen. Postero-lateral view of the type. (After Wachsmuth and Springer, North American Crinoidea Camerata, pl. 79, fig. 8.)

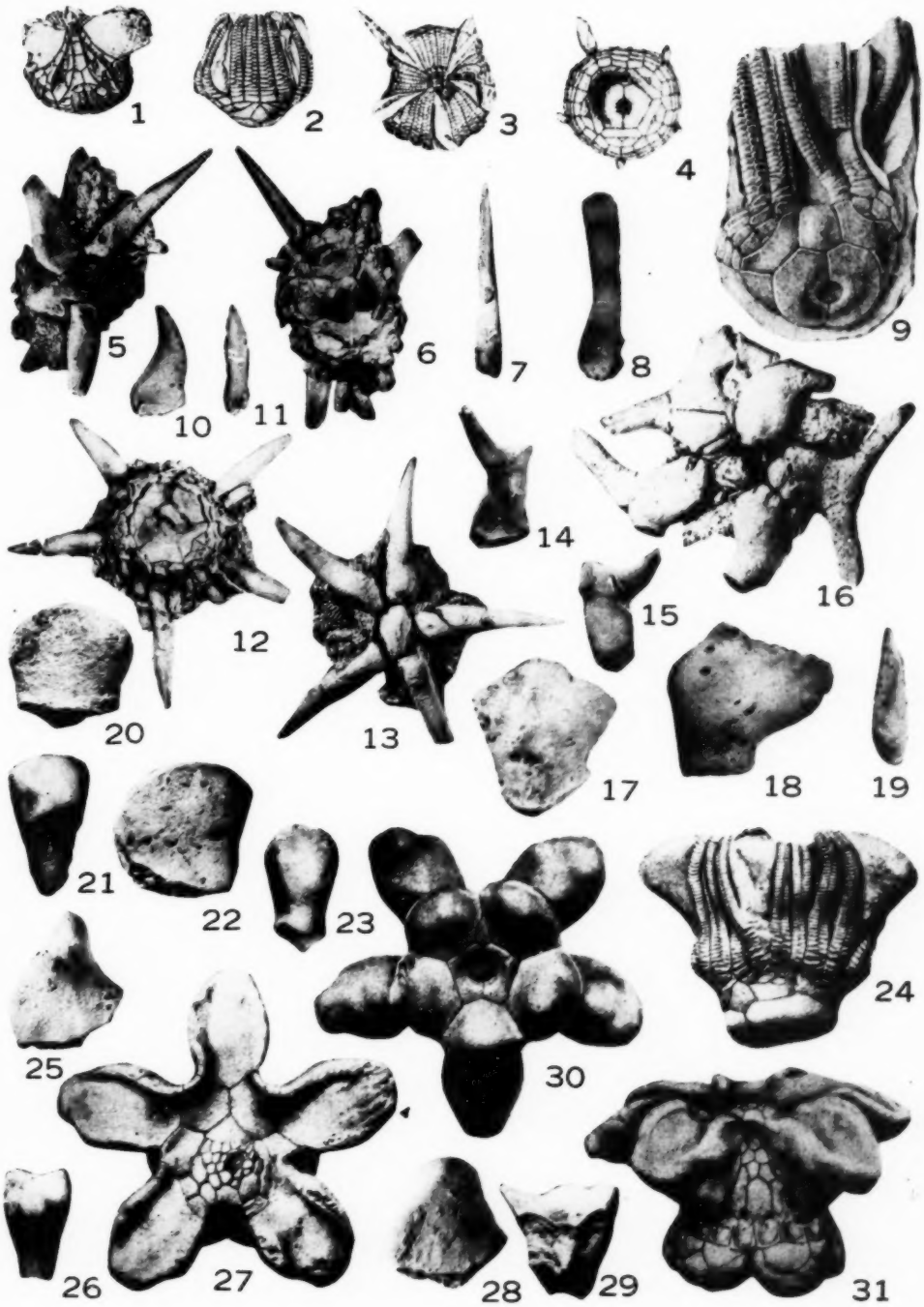
10–13—*Pterotocrinus acutus* Wetherby. 10, 11, Lateral and ventral views of an appendage, plesiotype, W. M., 26711. 12, 13, Dorsal and ventral views of a nearly complete specimen, the holotype, W. M., 6403. Both views turned slightly to the left.

14–16—*Pterotocrinus bifurcatus* Wetherby. 14–15, Lateral and ventral views of an appendage showing only one prong. 16, Ventral view of the holotype, W. M., 6401. (After Weller, Ill. Geol. Survey, Bull. 41, pl. 10, fig. 14.)

17–19—*Pterotocrinus scapulatus* Sutton, n. sp. 17, Lateral view of cotype, W. M., 37308. 18, 19, Lateral and ventral views of cotype, W. M., 9391.

20–24—*Pterotocrinus capitalis* (Lyon). 20, 23, Lateral and anterior views of a perfect appendage. 21, 22, Anterior and lateral views of another specimen showing difference in shape. Plesiotypes, W. M., 30247A. 24, Postero-lateral view of the type specimen. (After Springer, U. S. Nat. Mus., Proc., vol. 67, art. 9, pl. 13, fig. 23). Plastoholotype, W. M., 15850.

25–31—*Pterotocrinus coronarius* (Lyon). 25, 26, Lateral and anterior views and 28, 29, Lateral and posterior views of two appendages, plesiotypes, W. M., 30535, 27, 30, 31, Ventral, dorsal, and antero-lateral views of the holotype. (After Springer, U. S. Nat. Mus., Proc., vol. 67, art. 9, pl. 14, figs. 1, 1*a*, 1*b*.)



Sutton, Mississippian crinoids

UNIV. OF IOWA

PTEROTOCRINUS CRASSUS Meek
and Worthen
Plate 50, figure 9

Dichocrinus (*Pterotocrinus*) *crassus* MEEK and WORTHEN, *1860*, Acad. Nat. Sci. Phil., Proc., p. 382.
Pterotocrinus crassus MEEK and WORTHEN, *1866*, Ill. Geol. Survey, vol. 2, p. 290, pl. 23, figs. 2*a–b*.—WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 801, pl. 79, fig. 8.

Dorsal cup basin-shaped, more than twice as wide as high. It is broad at the base with less spreading sides than most species, and constricted at the suture between the basals and radials. Basals large, forming a shallow cup, concave below, which widens from the lower margin to the basi-radial constriction. Radials slightly convex, wider than high and rapidly expanding in width upward. The upper surfaces are concave and support the primibrachs, secundibrachs, and outer tertibrachs of the proximal row. Anal plate quadrangular, wider below than above. Triangular primibrachs very small, secundibrachs and lower tertibrachs larger and approximately equal. Arms free beyond the first tertibrachs and biserial above the third. The appendages are thinner distally and thicker at the base, the exact form not known. Structure of the tegmen unknown. Column small occupying about one-fourth of the basal cavity.

The relationship of this with other species is not determinable. It would appear to be most probably related to some member of the *P. armatus* gens, judging from the incomplete "wing plates."

Kaskaskia (Chester) series in Hardin County, Illinois. Illinois State collection, Springfield.

PTEROTOCRINUS PYRAMIDALIS Lyon
and Casseday
Plate 49, figures 19, 20

Pterotocrinus pyramidalis LYON and CASSEDAY, *1860*, Am. Jour. Sci., (2), vol. 29, p. 69.—SHUMARD, *1866*, St. Louis Acad. Sci., Trans., vol. 2, p. 394.—WACHSMUTH and SPRINGER, *1897*, North American Crinoidea Camerata, p. 798, pl. 79, figs. 4*a–b*. —SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 50, pl. 13, figs. 21–22.

Calyx medium size. Dorsal cup saucer-shaped, truncate below with rapidly expanding sides, particularly above the radials. Plates thick and unornamented. Basal plates broadly concave below and notched for the reception of the anal plate. Radials subquadrangular, considerably wider above than below and concave along the superior edge in contact with the primibrachs, secundibrachs, and the outer tertibrachs of the proximal row. Anal plate large, lozenge-shaped with the upper end bent inward. Primibrachs triangular and very small. Secundibrachs irregularly polygonal and smaller than the tertibrachs. The first two rows of tertibrachs fixed, forming part of the calyx, and larger than the third row. Arms four in each ray, and biserial above the third row of tertibrachs. Tegmen pyramidal with flattened or slightly concave sides, longitudinally grooved for the reception of the arms. The four regular interambulacral areas are each composed of an oral plate and three equal plates in two rows, all plates longer than wide. The first plate is hexagonal and the next two pentagonal. The two upper plates and the oral are beveled to receive the appendages. The anal interambulacral is composed of two plates in the first row, three in the second followed by numerous smaller pieces. The posterior oral is pushed forward between the other four. Anal opening subcentral.

The form of the appendages is not definitely known but the narrow elongate sockets suggest an appendage relatively thin at least in the proximal portion. Column round and smaller than the basal cavity.

It has been impossible from the limited material available to place this species in relation to any of the three gentes.

Glen Dean limestone in Edmonson, Grayson, and Breckenridge counties,

Kentucky, and Morton County, Indiana. Lyon collection.

PTEROTOCRINUS RUGOSUS Lyon and Casseday
Plate 49, figures 21, 22

Pterotocrinus rugosus LYON and CASSEDAY, *1860*, Am. Jour. Sci., (2), vol. 29, p. 71.—SPRINGER, *1926*, U. S. Nat. Mus., Proc., vol. 67, art. 9, p. 47, pl. 13, figs. 17–20.

This species, originally founded on a single crushed and imperfect specimen, was described but not figured. Springer redescribed and figured it. Dorsal cup low and saucer-shaped only slightly convex on the lower part. The columnar cavity deep and much larger than the column. The arrangement and number of plates in the calyx are similar to those in *P. depressus* but the plates are much thicker, the base more prominent, and the basal and radial plates are marked by knobby protuberances. The plates of the dorsal cup are separated by pronounced sutures and the columnar cavity is much more prominent than in *P. depressus*.

The appendages are only imperfectly known but appear similar to those of *P. depressus* in being thin and expanded. This species, however, is readily distinguishable from *P. depressus* by the characters of the dorsal cup noted above.

Judging from the portions of the "wing plates" preserved in the specimens which the writer has observed, there can be no question that this species is a member of the *P. depressus* gens, very closely related to *P. depressus*.

Glen Dean limestone, Falls of Rough Creek, Breckenridge County, Kentucky. Holotype in the Lyon collection, Plesiotype, Walker Museum, 19144.

PTEROTOCRINUS WETHERBYI Miller and Gurley
Plate 50, figures 1–4

Pterotocrinus wetherbyi MILLER and GURLEY, *1895*, Ill. State Mus. Nat. Hist., Bull. 6, p. 44, pl. 4, figs. 6–9.

Calyx medium size. Dorsal cup low and saucer-shaped, more than twice as wide as high. Surface finely granulose, sutures not deeply impressed. Column small and round, deeply inserted and occupying only a portion of the columnar cavity which is surrounded by a sharp rim. Anal plate quadrangular. Radials pentagonal or hexagonal and from three to four times as wide as high, straight or very slightly concave along the upper edge. Primibrachs small and triangular resting in the center of the upper edge of the radials. Secundibrachs irregularly pentagonal and about twice as wide as high. Tertibrachs to the third or fourth, incorporated in the calyx. Arms biserial above the fourth or fifth tertibrach and infolding over the top leaving the apex of the tegmen exposed. Tegmen pyramidal, furrowed and composed of large plates. Appendages more or less leaflike and set in rather broad angular notches in the tegmen. They are thickest about midway of the length and taper to a knife-like margin. Complete "wing plates" are not known.

This species in a number of respects resembles more or less *P. depressus*. However, the portions of the "wing plates" preserved exhibit the greatest thickness about midway of the length as in the case of *P. vannus* and unlike *P. depressus*. Its position in the evolutionary scheme has not been determined.

Kaskaskia (Chester series) in Pulaski County, Kentucky. Cotypes, Gurley collection, Walker Museum, 6417.

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BITUBULOGENERINA, A TERTIARY NEW GENUS OF FORAMINIFERA

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ABSTRACT

The genus *Tubulogenerina* was erected by Cushman in 1927. Since that date three American Tertiary species have been placed under that genus. These are *T. aperta* Cushman, Oligocene of Mississippi, *T. eocenica* Cushman and Ellisor, Eocene of Texas, and *T. vicksburgensis* Howe, Oligocene of Mississippi. The last mentioned species is considered a true *Tubulogenerina*, but the first two are placed under *Bitubulogenerina* Howe (new genus). *B. vicksburgensis* Howe, n. sp., from the Oligocene of Vicksburg, Mississippi, is selected as the genotype. Other new species erected are *Bitubulogenerina mauricensis* from the Claiborne Eocene at St. Maurice, Louisiana, *B. montgomeryensis* from the Jackson Eocene at Montgomery, Louisiana; *B. hiwanneensis* from the Red Bluff Oligocene at Hiwannee, Mississippi; and *Tubulogenerina jacksonensis* from the Jackson Eocene at Bunker Hill, Louisiana. While the genus *Tubulogenerina* is represented in the American Tertiary by two species, one upper Eocene in age, the other Oligocene, the genus *Bitubulogenerina* is represented by at least six species and has a range from Claiborne (Eocene) to Byram marl (Oligocene).

The genus *Tubulogenerina*, erected by Cushman in 1927, has been the subject of such varying interpretations that the writer feels it necessary to give an historical outline of the published opinions concerning it. Cushman's (3, p. 78) original description and accompanying discussion of the genus is quoted in full:

Genotype, *Textularia* (*Bigenerina*) *tubulifera* Parker and Jones, *Annals Mag. Nat. Hist.*, (3) vol. 11, p. 94, fig. 2 (in text), 1863.

Test with the early chambers biserial, later ones uniserial, compressed or rounded in transverse section; wall with numerous tubuli extending out from the test either open, forming a tubular connection with the interior, or closed, forming tubular connections with the chamber; wall calcareous; aperture elongate, narrow or in the adult with numerous rounded openings in the terminal face, the interior of the chambers at least in some species with a curved structure from roof to floor.

This genus occurs in the upper Eocene of the Paris Basin and in the Miocene of Australia. It was originally figured in the above reference from Grignon by Parker and Jones. Later Terquem in 1882 (*Mém. Soc. Géol. France*, ser. 3, vol. 2, p. 121, pl. 12, fig. 35 *a*, *b*) referred it to *Clavulina eocenica* Gümbel. Heron-Allen and Earland (*Roy. Micr. Soc., Jour.*, p. 329, pl. 16, fig. 1, 1909) had a specimen from the Eocene of Selsey and recognizing that Terquem's placing of the species was erroneous gave it a new name *Bigenerina conica*, not recognizing the earlier name of Parker and Jones. Heron-Allen and Earland place under *B. conica* much larger specimens from the Miocene of Australia (Pl. 16, figs. 2–6) which from a study of specimens in my own collection from the Filter Quarry of Moorabool River and a comparison with *T. tubulifera* from the Eocene of the Paris Basin appears to be a different species. The Australian species is much larger, has the biserial development much more restricted, the rows of tubules two or three in the adult whereas they are usually single in the Eocene species. This Australian Miocene species may be known as *Tubulogenerina mooraboolensis* Cushman, new species. Other species are *Tubulogenerina ferox* (Heron-Allen and Earland) from the same locality and *T. papillosa* (Halkyard) from the Eocene of Biarritz.

In the above description Cushman did not give the family relationship of *Tubulogenerina*. His *Reclassification of the Foraminifera*[1] published three months later does not mention the genus. The following year, however, in his text *Foraminifera, their classification and economic use* (4, p. 252), he placed *Tubulogenerina* under Subfamily 4. Virgulininae of Family 31 Buliminidae. The genus was not redescribed, but the range of the genus was extended so as to read "Cretaceous to Miocene," and in the *Key to genera* (p. 243), he stated: "Aperture cribrate or a circle of pores."

In 1929, Cushman (5, pp. 45–46) described a small species from "Byram calcareous marl, Byram, Mississippi," under the name "*Tubulogenerina aperta*,"—a species which the writer here places under *Bitubulogenerina* (n. gen.). In the synonymy of this species he placed "*Gaudryina* sp.?" described and figured previously by him (2, p. 127) from the Mint Spring marl at Vicksburg, Mississippi. In the ensuing discussion of the species, he again gave the range of the genus *Tubulogenerina* as Cretaceous to Miocene.

The following year Howe (6, p. 351) described *Tubulogenerina vicksburgensis* from the Byram Marl at Byram, Mississippi. Before doing so, he sent a specimen to Cushman, who, after comparing it with the type species of the genus, wrote:[2] "As to the *Tubulogenerina*—yours is a true member of the genus and somewhat close to the Paris Basin species, but I think undoubtedly new."

Two years later, 1932, Cushman and Ellisor (7, p. 42) described "*Tubulogenerina eocenica*" from a well sample in the Humble field, Harris County, Texas, stating that its age was Eocene (Jackson). In their description of the chamber arrangement of this species they state: "earlier portion *triserial*, later adult portion biserial and *tending* in the larger specimens to become uniserial." The italics are the writer's. He considers this species to be a typical *Bitubulogenerina*.

This description was probably responsible for Galloway's (8, p. 349) comment: "This genus is not well understood. The early part may be triserial. Cushman says the aperture is cribrate, although figures show only one aperture." He redescribed the genus as follows:

> Test free, elongate conical, oval or round in transverse section; early chambers biserial, later ones uniserial, short and broad; wall calcareous, with numerous tubuli extending out on all sides, which are open or closed, aperture oval or fissurine, terminal. Length up to 1 mm. —Shallow water deposits. Eocene of the Paris Basin and England, Miocene of Australia.

Galloway, likewise, in his *Key to genera* (p. 347) indicated that it was to be recognized by being "Uniserial in the adult, test not flabelliform, with mural tubuli." He placed the genus *Tubulogenerina* in Subfamily 2 Gümbelininae under the family Heterohelicidae, next to *Rectogümbelina*, from which genus he indicated it is to be separated by means of the "mural tubuli."

Galloway's Manual was followed in a few months by the second edition

[1] Cushman, J. A., *Contrib. Cushman Lab. Foram. Research*, vol. 3, pt. 1, 105 pp., March, 1927.

[2] Personal letter from J. A. Cushman under date of Jan. 8, 1930.

of Cushman's *Foraminifera, their classification and economic use*, (9, p. 222) in which the genus *Tubulogenerina* is again redescribed:

> Genotype, *Textularia* (*Bigenerina*) *tubulifera* Parker and Jones. Test with early stages biserial, sometimes triserial in the microspheric form, adult uniserial, compressed or rounded in section, wall calcareous, perforate, with numerous tubuli extending out from the test, either open or closed, forming lobular connections with the chamber, aperture elongate, narrow, or in the adult numerous rounded openings in the terminal face, interior in some species with a curved structure from roof to floor in the biserial portion.—Eocene to Miocene

In the accompanying Key, under Family 30 Buliminidae, (page not given) he again indicates that the genus may be recognized by an "Aperture cribrate or a circle of pores." The genus is again placed in Subfamily 4 Virgulininae.

In a recent paper Miss Ellisor, (10, pp. 1303, 1344) under the name "*Tubulogerina* (sic) *eocenica* Cushman and Ellisor," refigures the species described a year earlier, and considered by the writer to be a typical *Bitubulogenerina*, and indicates that it occurs in the Caddell formation, basal Jackson Eocene.

Cushman, in his papers, has not refigured *Tubulogenerina tubulifera* (Parker and Jones), the type species, but in his text-book figures *T. mooraboolensis* from the Miocene of Australia instead. This latter species is certainly very similar to *T. vicksburgensis* Howe from the Oligocene of Mississippi and to *T. jacksonensis* Howe, n. sp. from the Eocene of Louisiana, at least in the character of the aperture and in the ornamentation. The writer has already noted Cushman's observation concerning the closeness of *T. vicksburgensis* to *T. tubulifera*. It would appear then that these four species at least are closely related. The writer has ob-

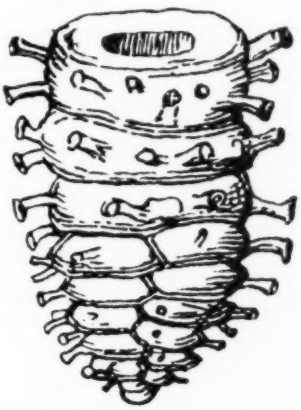


FIG. 1. *Tubulogenerina tubulifera* (Parker and Jones); a copy of Galloway's reproduction of the original figure of the type species of the genus *Tubulogenerina*.

tained two excellent samples from Grignon, the type locality of *T. tubulifera*, through the courtesy of Doctor Cushman, but careful bromoforming failed to produce anything similar to the original figure of the species by Parker and Jones. He is therefore including a copy (text figure 1) of Galloway's reproduction of the original figure. This figure appears to be somewhat generalized and the writer doubts the accuracy of the drawing of the aperture. Nevertheless the figure does clearly show the earliest chambers to be triserial in their arrangement. In the light of the confusion which has existed concerning the genus *Tubulogenerina* and in the absence of a topotype specimen of *T. tubulifera*, the writer has some hesitation in attempting to redescribe the genus, but feels that he should at least outline his views concerning it.

Genus TUBULOGENERINA Cushman, 1927

Test free, elongate, oval or round in cross section; triserial in the earliest chambers, probably biserial in many megalospheric specimens, becoming distinctly uniserial in the adult; wall calcareous, hyaline, with numerous tubuli, protuberances or hollow bumps extending from the sides of the chambers; aperture ovate? (if Parker and Jones figure is correct) or fissurine, and terminal. Eocene of the Paris Basin and of Louisiana; Oligocene of Mississippi; Miocene of Australia.

The writer does not place *Tubulogenerina* in any described family. He feels that it is a direct outgrowth of *Bitubulogenerina*, n. gen., which in turn is a descendent of some triserial ancestor as yet undescribed, and that these forms are representatives of a group all their own.

TUBULOGENERINA JACKSONENSIS Howe, n.sp.
Plate 51, figures 8 *a*, *b*

Test free, elongate, subcircular in outline; early chambers triserial, later ones uniserial, the uniserial portion consisting of from three to seven chambers, each ornamented with numerous tuberculated ridges whose greatest length is parallel to the elongation of the test; aperture an arcuate slit on the otherwise smooth terminal face.

Length, 0.23 mm.; diameter, 0.14 mm.

The holotype, No. 748, Howe collection, is a single specimen found in the Jackson Eocene at Bunker Hill, on the Ouachita River, Louisiana. Its horizon is approximately that of the Moody's Branch marl of Mississippi, i.e., basal Jackson. Another specimen (paratype No. 749) with seven uniserial chambers, but otherwise identical, was found in an abandoned lime pit 5.1 miles south of Ocala, Florida, on the road to Belleview. From the associated foraminifera, the writer feels that it came from the basal Jackson also.

Genus BITUBULOGENERINA Howe, n. gen.

Test free, with early stages triserial, in some megalospheric specimens with the triserial portion greatly reduced, adult biserial; wall calcareous, hyaline, perforate, with numerous tubuli protuberances or hollow bumps extending from the sides of the chambers; aperture ovate or angular, tending to be siphonate in most specimens, with a distinct lip, terminal, and tending to overlap the preceding chamber. Eocene to Oligocene.

BITUBULOGENERINA VICKSBURGENSIS Howe, n. sp.
Plate 51, figures 7 *a*, *b*

Test free, elongate; early chambers rounded, nodose, triserial in arrangement, quickly becoming biserial and

EXPLANATION OF PLATE 51

FIGS. 1 *a–b*—*Tubulogenerina vicksburgensis* Howe, from Byram marl, Byram, Mississippi. *a*, Side view, ×125. *b*, Apertural view, ×125.

2 *a–b*—*Bitubulogenerina hiwanneensis* Howe, n. sp., from Red Bluff Oligocene, Hiwannee, Mississippi. *a*, Side view, ×175. *b*, Apertural view, ×175.

3 *a–b*—*Bitubulogenerina aperta* (Cushman), from Byram marl, Byram, Mississippi (after Cushman). *a*, Edge view, ×130. *b*, Apertural view, ×130.

4—*Bitubulogenerina* sp. (Cushman) from Mint Spring marl, Vicksburg, Mississippi (after Cushman, *U. S. Geol. Survey, Prof. Paper.* 129, pl. 29, fig. 6). Side view, ×130.

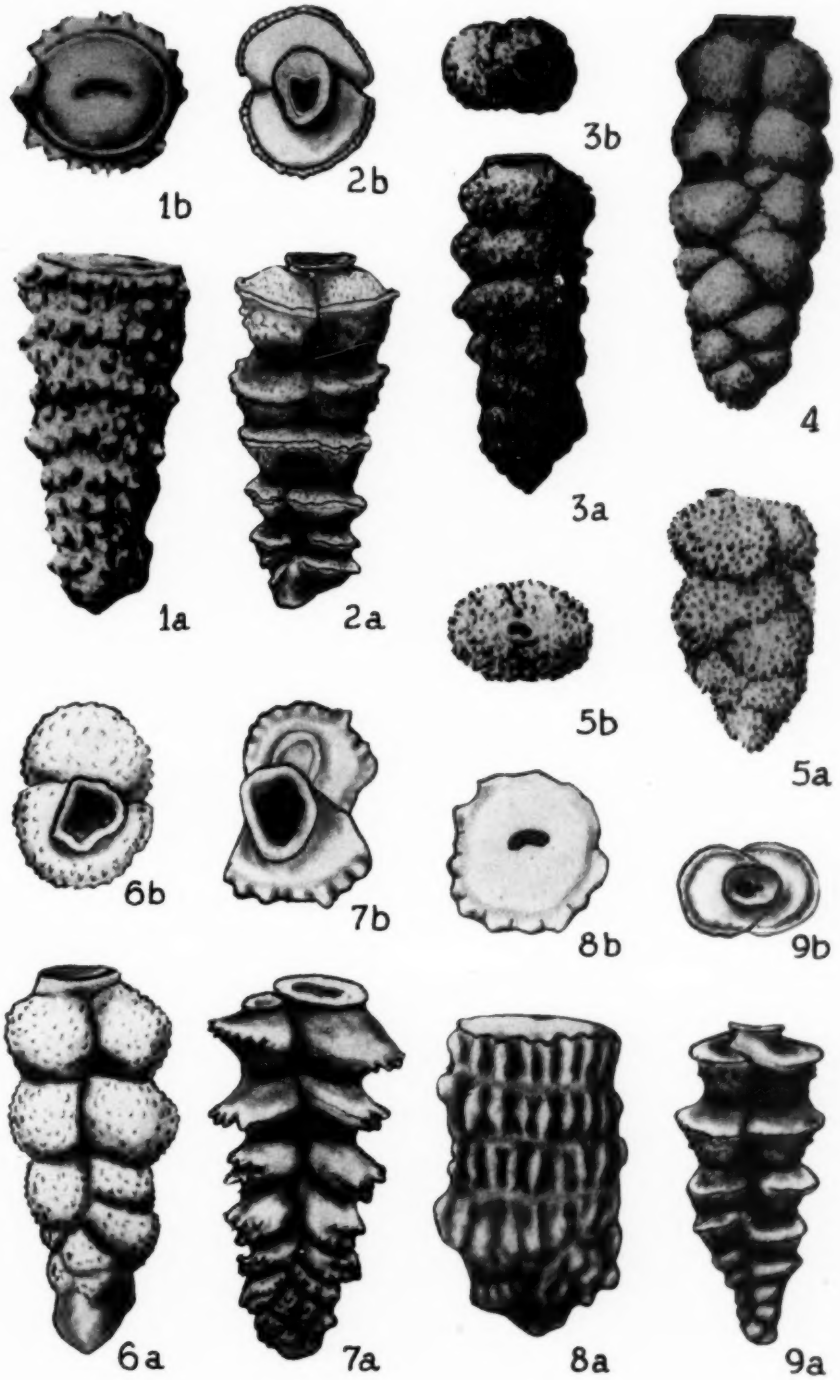
5 *a–b*—*Bitubulogenerina eocenica* (Cushman and Ellisor), from Jackson Eocene of Texas (after Cushman and Ellisor). *a*, Side view, ×120. *b*, Apertural view, ×120.

6 *a–b*—*Bitubulogenerina mauricensis* Howe, n. sp., from Claiborne Eocene, St. Maurice, Louisiana. *a*, Side view, ×170. *b*, Apertural view, ×170.

7 *a–b*—*Bitubulogenerina vicksburgensis* Howe, n. sp., from Oligocene of Vicksburg, Vicksburg, Mississippi. *a*, Side view, ×173. *b*, Apertural view, ×173.

8 *a–b*—*Tubulogenerina jacksonensis* Howe, n. sp., from Jackson Eocene, Bunker Hill, Louisiana. *a*, Side view, ×190. *b*, Apertural view, ×190.

9 *a–b*—*Bitubulogenerina montgomeryensis* Howe, n. sp., from Jackson Eocene, Montgomery, Louisiana. *a*, Side view, ×190. *b*, Apertural view, ×190.



Howe, Tertiary Foraminifera

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angular, the chambers of the medial portion of the test carry two rows of tubular projections, later chambers carry only a fringe of nodose tubuli about the angular periphery; aperture terminal, siphonate, the lip being ovate in outline, but the apertural opening being subtriangular; aperture of preceding chamber usually visible as a distinct swelling, but filled with calcareous material.

Length, 0.28 mm.; width, 0.15 mm.

The holotype, No. 750, Howe collection, is from the top of the limestone bed which causes the waterfalls of Mint Spring Bayou, Vicksburg, Mississippi. The species is common at this station.

BITUBULOGENERINA MAURICENSIS Howe, n. sp.

Plate 51, figures 6 *a*, *b*

Test free, elongate; early chambers rounded, nearly smooth, triserial in arrangement, the triserial portion forming about one-third the length of the test; later adult portion biserial; chambers distinct, globular, and ornamented with numerous spinose projections in the biserial portion; wall calcareous; aperture terminal, angular and with a short neck.

Length, 0.29 mm.; width, 0.13 mm.

This species is closely related to *B. aperta* (Cushman) but has many fewer chambers, is thicker, and the aperture is subquadrate, rather than ovate in outline. It can be quickly separated from *B. eocenica* (Cushman and Ellisor) as its aperture is much larger and of very different shape.

BITUBULOGENERINA MONTGOMERYENSIS Howe, n. sp.

Plate 51, figures 9 *a*, *b*

Test elongate, free, somewhat compressed; the first few chambers rounded and triserial in arrangement, quickly becoming biserial, and as the chambers are added they become more and more angular, the angulations being above the middle of the chamber; wall nearly smooth above the angulation, but spinose below; aperture siphonate with a short neck, the phialine lip being oval in outline, the apertural opening being small and spade-shaped.

Length, 0.23 mm.; width, 0.11 mm.

Holotype from the basal Jackson Eocene at Montgomery, Louisiana. The species is common at this locality and also at Gibson Landing, Bunker Hill, and Grandview bluff on the Ouachita River, Louisiana; Jackson, Mississippi, and other basal Jackson Eocene localities.

BITUBULOGENERINA HIWANNEENSIS Howe, n. sp.

Plate 51, figures 2 *a*, *b*

Test elongate, free; first few chambers triserial, quickly becoming biserial and angular, the angulation being at or just above the middle of the chambers; wall calcareous and finely spinose; aperture siphonate with a short neck, subcircular lip and slightly crescentric opening.

Length, 0.27 mm.; width, 0.12 mm.

Holotype from Red Bluff Oligocene at Hiwannee, Mississippi, where the species is not rare. This species is related to *B. montgomeryensis* but differs in its more nearly circular outline, in the position of the angulation, and in the fact that nearly all the chambers are angulated.

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JOURNAL OF PALEONTOLOGY, VOL. 8, NO. 4, PP. 422–432, PLS. 52–55, DECEMBER, 1934

SOME MID-PENNSYLVANIAN INVERTEBRATES FROM KANSAS AND OKLAHOMA: I. FUSULINIDAE, BRACHIOPODA[1]

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ABSTRACT

Two new species and one new variety of fusulinids, and nine brachiopods, seven of which are new, are described in this paper. Of the brachiopods *Chonetella?*, *Avonia*, and *Parenteletes* are recorded for the first time in the Mid-Continent region and the first two are apparently new to the North American Pennsylvanian. The occurrence of *Schizophoria* in beds of mid-Pennsylvanian age is unique for North America.

This paper is the first of a series of articles devoted primarily to the description of new species that were found during a recent study of the faunas of the upper part of the Missouri series. This series, as here recognized, is restricted to include strata between the Des Moines and Virgil series as defined by R. C. Moore; that is, between disconformities located respectively in the Pleasanton shale and Douglas group as formerly classified. Forthcoming papers will be devoted to corals, sponges, gastropods, and cephalopods.

I wish to acknowledge the constructive criticism of Doctors J. Brookes Knight, Carl O. Dunbar, and R. C. Moore. Doctor Moore made the accomplishment of the project possible through the facilities of the Kansas Geological Survey.

DESCRIPTION OF SPECIES

Genus TRITICITES Girty

TRITICITES NEGLECTUS Newell, n. sp.
Plate 52, figures 2*a–b*; Plate 53, figures 1*a–b*

The test is of moderate size, slender, bluntly fusiform or subcylindrical, commonly with symmetrical growth, although some specimens exhibit some irregularity near the poles. The dimensions of five representative specimens are:

Axial length	Diameter
5.9 mm.	2.2 mm.
7.0	2.4
6.0	1.7
8.0	2.0
8.5	2.5

The form ratio ranges between 3.7/1 and 4.5/1. The number of volutions in mature individuals is 6.5 to 8. The number of septa in the third volution is 21 or 22, in the fourth 23 to 25, and in the fifth 25 to 27. The septal fluting is characteristically rather intense in an axial zone and in the polar extremities, where the vesicular tissue is crowded to form relatively small interspaces. The septa are fluted regularly across the mid-portions in all excepting the last volution, and

[1] From a dissertation presented at Yale University as a partial requirement for the degree of Doctor of Philosophy: "The stratigraphy and paleontology of the upper part of the Missouri series in eastern Kansas."

even in this one the septa are in some instances distinctly fluted across the length of the shell, but the amplitude of the septal folds is relatively slight so that the chambers between septa are not divided into distinct chamberlets. Septal pores seemingly are absent in most individuals, but in some instances a few pores of moderate size occur at the ends of the axial zone. The chomata are moderately narrow and rise from one-third to one-half of the height of successive volutions and generally extend to the last half volution. The tunnel in a very few specimens is irregularly disposed with respect to the sagittal plane but more commonly it is symmetrical, flaring outward from between 31 and 44° in the first five volutions to about 65° in the outer whorls. The proloculum is characteristically small ranging in diameter from about 80 to 135 microns. The walls are thin, ranging between 18 and 30 microns in the fourth volution, and 35 or 55 microns in the sixth volution. The lamellae of the keriotheca are spaced so that about seven occur in a distance of 100 microns.

Discussion.—This species is one of the common Lansing forms classed indiscriminately in current usage with *Triticites irregularis*. Dunbar[2] regards as typical *T. irregularis* the form occurring abundantly in the Winterset limestone at Winterset, Iowa. As compared with that form, *T. neglectus* generally lacks the radial constrictions and irregular growth of the Winterset form and exhibits markedly more intense septal fluting. The septa in *T. irregularis* appear strikingly plane across the middle third of the shell length, resembling *T. secalicus* in this respect, and the fluting along the axial zone occurs in relatively large, open loops. In the present species, however, the septa are noticeably fluted entirely across the shell and the loops of the axial zone are small and crowded. The new species is a slightly more robust form than *T. irregularis* and has markedly thinner walls. The number of volutions in *T. neglectus* generally exceeds the number in *T. irregularis*.

Distribution.—The new species is common in the Captain Creek limestone member of the Stanton formation. The types were collected from this horizon at the NE. cor. sec. 4, T. 13 S., R. 21 E., and at an old quarry two-tenths of a mile north of Pressonville at the center of the E. side sec. 26, T. 16 S., R. 21 E., Miami County, Kansas.

[2] Dunbar, C. O., personal communication.

TRITICITES OSAGENSIS Newell, n. sp.
Plate 52, figure 4*a–f*; Plate 53, figure 4

The shell is elongate, slender, and cylindrical with somewhat blunt or broadly acute termini. Commonly the axis is slightly arcuate and the terminal extensions exhibit irregular growth. The dimensions in seven average specimens are:

Axial length	Diameter
9.5 mm.	1.6 mm.
10.0	2.0
11.0	2.0
9.0	1.5
10.0	1.9
9.5	1.5
9.6	1.6

The average ratio of length to diameter in these specimens is 5.7/1.

The proloculum is exceedingly minute, measuring in three specimens 60, 82, and 105 microns, respectively. The volutions commonly number seven or eight in large specimens. The septal count in the third volution is about 19 or 20, the fourth 19 to 24, fifth 21 to 25. The thickness of the wall in the fourth volution is 15 microns and in the sixth volution 45 to 52 microns. The tunnel is generally somewhat irregularly disposed so that in successive volutions it may lie on either side of a sagittal plane. The tunnel angle is commonly small in the inner volutions, flaring abruptly in the outer whorls to 50 or 60° in the sixth volution. The septal spores are abundant in the outer three or four volutions, and

coarse, ranging in diameter between about 11 and 14 microns. The septal fluting is very intense for a triticite, extending two-thirds or more toward the base of each septum. Tangential sections show closed septal loops along the lower margin of the septa. The loops give way near the outer margins of the chomata and the fluting, although slight, is nevertheless distinct across the last volution. There is an intense development of vesicular tissue along the axial zone. The chomata are relatively narrow and high, as a rule occupying from a third to a half of the height of a volution, and are lacking only in the last volution. The wall texture is coarse, 76 lamellae being distributed through 1 mm.

Discussion.—This species is one of the group of *T. irregularis*. From the similar *Triticites neglectus*, n. sp., *T. osagensis* may be distinguished by its great axial length, minute proloculum, thin walls, and more intense septal fluting. A notable feature of the shell in *Triticites osagensis* is the abrupt thickening of the wall after the fifth volution, the wall in the sixth whorl being nearly twice as thick as that of the preceding one.

Distribution.—This species as far as is known seems to be confined to the Oklahoma facies, occurring alone in sandy limestone or calcareous sandstone. It characterizes the "Fusulina limestone" of eastern Osage County, Oklahoma. The types were collected at a road-cut on highway 11, 2 miles north of Avant, in the SW. ¼, sec. 31, T. 24 N., R. 12 E. Molds of a similar form occur in the calcareous sandstone capping the bluffs 4 or 5 miles northwest of Bartlesville, Oklahoma. These occurrences are probably equivalent to some part of the Stanton formation.

TRITICITES SECALICUS var. ORYZIFORMIS Newell, n. var.

Plate 52, figures 3*a–d*; Plate 53, figure 3

The shell is of moderate size, elongate, with rather bluntly acute ends. The dimensions of five mature specimens are, respectively:

Axial length	Diameter
5.9 mm.	2.2 mm.
7.0	2.4
6.0	1.7
8.0	2.0
8.5	2.5

The ratio of length to diameter ranges between about 2.6/1 and 4/1. In mature individuals the volutions number seven or eight and the septal count is rather low. The number of septa in the third

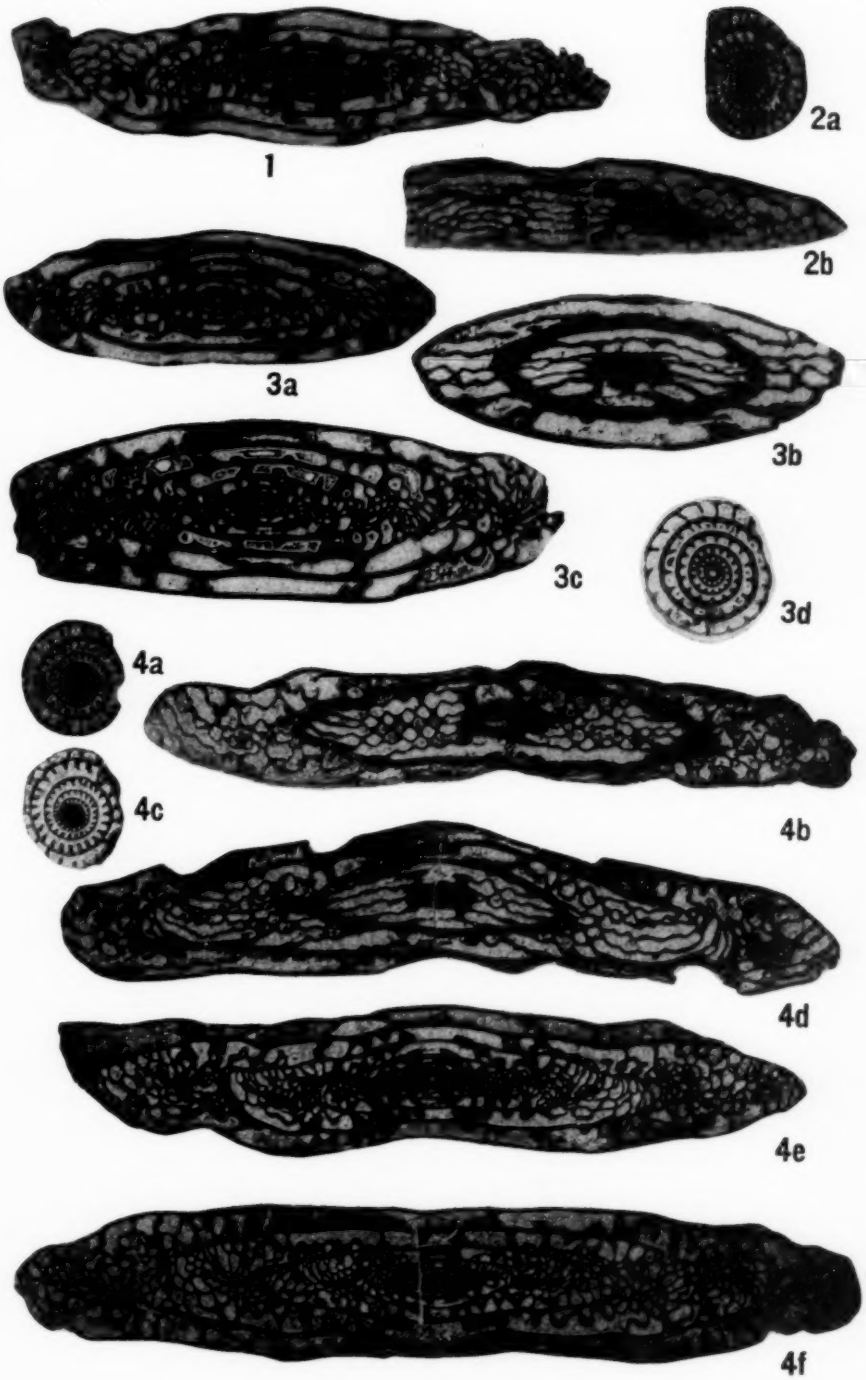
EXPLANATION OF PLATE 52

FIGS. 1—*Triticites irregularis* (Schellwien and Staff) emend. Dunbar and Condra, ×10, after Dunbar and Condra. This illustration is introduced for comparison. The specimen from the Winterset limestone at Winterset, Iowa, (originally stated Dekalb ls.) is thought by Dunbar and Condra to represent typical *T. irregularis*. (p. 423)

2*a*, *b*—*Triticites neglectus* Newell, n. sp., ×10. *a*, Sagittal section of a paratype from the Captain Creek ("Meadow") member of the Stanton formation near Eudora, Kansas. *b*, Tangential section showing the low amplitude of the septal folds, same locality and horizon. (p. 422)

3*a–d*—*Triticites secalicus* var. *oryziformis* Newell, n. var., ×10. Specimens from the "Westphalia" limestone (Douglas). *a*, Topoparatype; *b*, topoparatype, tangential section showing the characteristic low fluting; *c*, holotype; *d*, topoparatype. (p. 424)

4*a–f*—*Triticites osagensis* Newell, n. sp., ×10. "Fusulina limestone," Avant, Oklahoma, Stanton equivalent. *a*, Topoparatype; *b*, topoparatype, showing the division of the chambers into separate chamberlets; *c*, topoparatype; *d*, topoparatype, tangential section intersecting the septa nearer the ceiling of the whorl at the middle than in *b*, showing that the amplitude of fluting decreases greatly toward the ceiling; *e*, topoparatype; *f*, holotype. (p. 423)



Newell, Pennsylvanian fusulinids

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volution ranges from about 13 to 16, in the fourth, 16 to 18, in the fifth, 16 to 19. The septa are nearly plane across the middle of the outer volutions, but are strongly fluted along a narrow axial zone, which flares slightly toward the polar extremities of the shell. Septal pores of moderate size occur in the polar parts of the outer volution. The chomata are well developed, relatively narrow, and occupy from one-fourth to one-half of the height of successive volutions. These structures are lacking in the latter one-half or three-fourths of the outer volution. The tunnel angle is small in the first three or four volutions, 38 to 45°, flaring outward rapidly after the fifth volution to 58 to 65°. The proloculum ranges in diameter between 100 and 130 microns. Commonly the thickness of the wall in the fourth volution ranges between 35 and 55 microns, and in the sixth volution between 55 and 90 microns. These figures are somewhat within the extreme limits of variation. The texture of the keriotheca is relatively coarse, 10 alveoli occupying a space of about 165 microns.

Discussion.—This variety is comparable to typical *Triticites secalicus* from the Oread limestone, being distinguished by its smaller size and less ventricose form. The new variety cannot be considered as immature *T. secalicus*, because the number of volutions in the variety compares with adult specimens of *secalicus* rather than immature ones. Furthermore, although my collections include thousands of specimens of the new variety, large and ventricose forms like *T. secalicus* are entirely lacking. Representative lots of the variety can be distinguished from the typical form of the species at a glance.

Distribution.—The "Westphalia" limestone of the Douglas group, just below the Haskell limestone, is characterized by great numbers of the new form. The types came from the center of the north side sec. 12, T. 21 S., R. 17 E., Anderson County, Kansas.

BRACHIOPODA

Genus SCHIZOPHORIA King

SCHIZOPHORIA TEXANA Girty?

Plate 54, figures 1*a–g*, 2*a–d*, 3*a–c*

?Schizophoria texana GIRTY, *1927*, U. S. Geol. Survey, Prof. Paper 152, p. 432, pl. 27, figs. 1–8.

Schizophoria texana GIRTY? NEWELL, *1931*, Jour. Paleontology, vol. 5, p. 267, pl. 31, figs. 28–30.

The shell is of moderate size, transversely subelliptical and somewhat inflated with a relatively long hinge-line which joins the lateral outlines at a definite angle. The ventral valve is provided with a shallow and broad sulcus. The dorsal valve is subhemispherical and in some specimens bears an obscure fold, though in others this feature is lacking. The anterior margin is slightly insinuate at the fold. As in related species, the surface bears fine radial tubular lirae which bear scattered holes on their summits representing the bases of fine spinules. The interior of the ventral valve exhibits a low and broad median ridge almost intermediate in form between *Orthotichia* and *Schizophoria*. An adult of average size has a length of 18 mm., width 19.5, thickness about 14 mm.

Discussion.—There are two reasons for uncertainty as to the identity of this form and *Schizophoria texana* Girty. In the first place, typical *S. texana* is a much older form. Lacking specimens of that species for comparison it is not possible to distinguish it from the specimens at hand, and it may be that the Bend species is distinct from the present one from the Stanton formation. In the second place, there is some question regarding the relationship of several similar Pennsylvanian species like the present one. *Orthotichia schuchertensis*, *Schizophoria texana*, and *Schizophoria huecoiana* were described by Girty, each without reference to the others, and they are sufficiently alike that they cannot readily be distinguished by reference to the literature.

Distribution.—*Schizophoria texana*? is quite abundant in the Olathe ("Stoner") member of the Stanton formation at Fredonia, Kansas. It has not been found elsewhere in the Mid-Continent area.

Genus PARENTELETES King, 1930

PARENTELETES COOPERI King?

Plate 54, figures 4*a–c*

?*Parenteletes cooperi* KING, R. E., *1930*, The geology of the Glass Mountains, Texas, Part II, Texas Univ., Bull. 3042, p. 49.

The species is represented by a single dorsal valve which is not sufficiently complete to afford a positive specific identification but shows clearly the generic characters of *Parenteletes*.

The shell is very large, measuring 37 mm. long and about 45 mm. wide, with a deep median sulcus which originates about 12 mm. in front of the beak of the dorsal valve. The lateral plications number three on either side with a faint suggestion of a fourth on the outer lateral slope. There is a distinctly flattened band about 2 mm. broad down the middle of the median sulcus and in this space the fine lirae of the band are parallel. The lirae multiply by bifurcation on the lateral slopes of the sulcus and fan out rising obliquely to the crests of the adjacent plicae. The same feature occurs somewhat less pronounced in the first lateral sulci and there is practically no flattened area in the outermost sulci, consequently there is no sharply differentiated zone of parallel lirae. The dorsal cardinal area is about 2.5 mm. high at the highest place.

Discussion.—The genotype of *Parenteletes*, *P. cooperi* King, was described from the upper part of the lower Gaptank of west Texas. It was found associated with a *Triticites* of the *irregularis* type.[3]

A personal examination of King's specimens of *Triticites* found in association with *Parenteletes cooperi* revealed that they are more closely akin to *T. neglectus*, n. sp., than to any described form. The association of *Parenteletes* and the *Triticites neglectus* in Texas and their occurrence in the Stanton in Kansas suggests a correlation of the Stanton formation with the upper part of the lower Gaptank.

The single specimen of *Parenteletes* at hand has been compared directly with the types of *P. cooperi* and there can be no doubt that they are congeneric, and they are probably conspecific.

Distribution.—The single dorsal valve of *Parenteletes cooperi*? was collected in an exotic facies of the Olathe ("Stoner") limestone of the Stanton formation at Fredonia, Kansas.

Genus AVONIA Thomas, 1914

AVONIA KNIGHTI Newell, n. sp.

Plate 54, figures 5*a–i*

The shells of this species are small, thin, subhemispherical, in some instances slightly transverse, having the sides and anterior slope regularly curved.

[3] King, P. B., The geology of the Glass Mountains, Texas, Part 1: *Texas Univ., Bull.* 3038, p. 44, section 4, 1930.

EXPLANATION OF PLATE 53

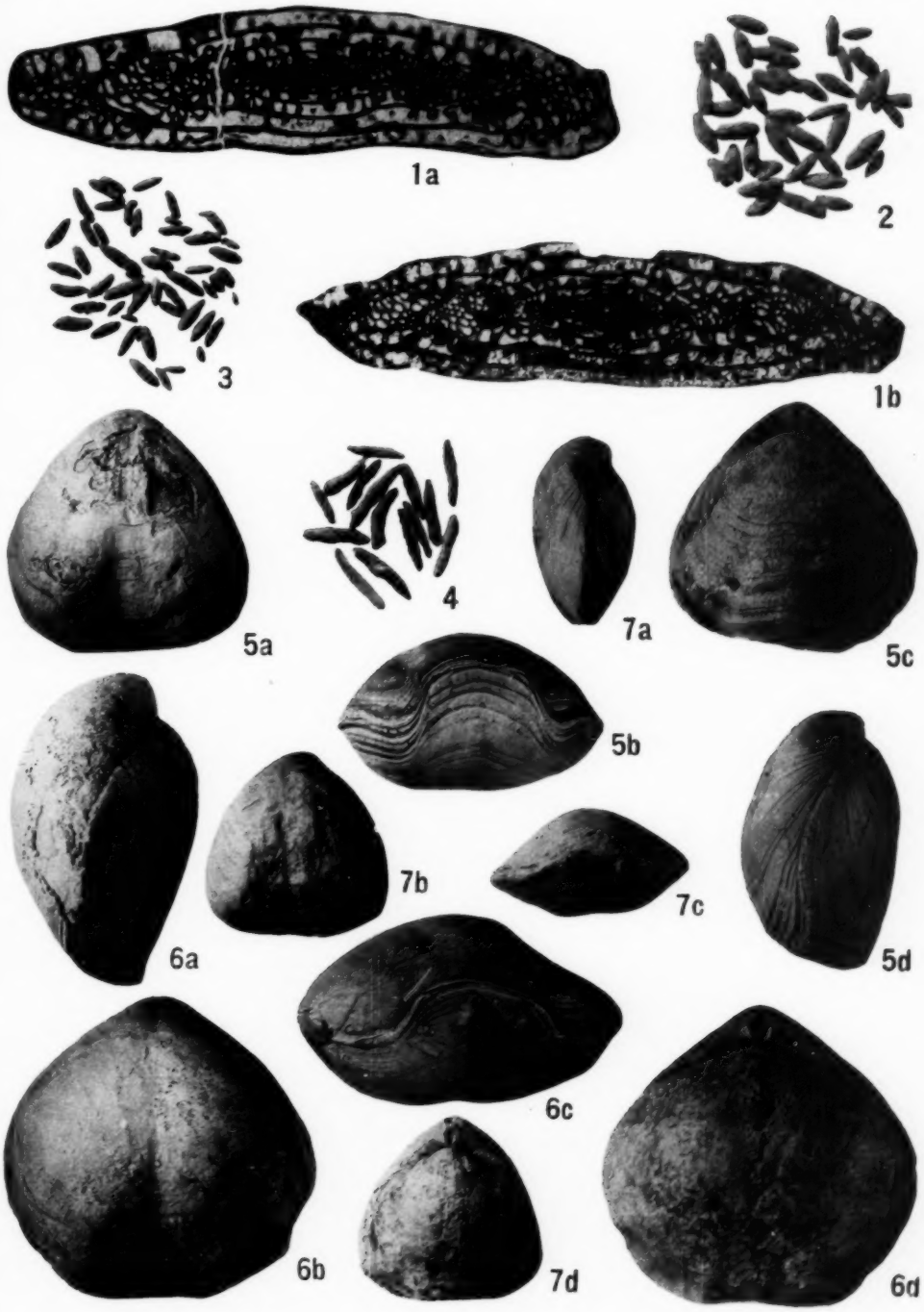
FIGS. 1*a*, *b*—*Triticites neglectus* Newell, n. sp., ×10. The holotype, Captain Creek ("Meadow") member of the Stanton formation, Miami County, Kansas; *b*, topoparatype. (p. 422)

2—*Triticites secalicus* (Say), ×1. A typical lot from the Oread formation introduced here for comparison. (p. 425)

3—*Triticites secalicus* var. *oryziformis* Newell, n. var., ×1. Topoparatypes. (p. 424)

4—*Triticites osagensis* Newell, n. sp., ×1. Topoparatypes. (p. 423)

5*a–d*, 6*a–d*, 7*a–d*—*Composita magna* Newell, n. sp., ×1. Top of the Plattsburg limestone, Bonner Springs, Kansas. 5*a–d*, The holotype, showing well the characteristic triangular form. 6*a–d*, An unusually robust and transverse topoparatype. 7*a–d*, A juvenile topoparatype. (p. 431)



Newell, Pennsylvanian fusulinids and brachiopods

SKIV. OF KIOH.

There is no trace of a ventral sulcus and the beak is small and sharp, extending behind the hinge only about one-fifth of the shell length and having the apex recurved and markedly dorsal to the hinge line. The surface of each valve is marked by concentric obscure lines of growth and by numerous, irregularly disposed erect spines. Those of the ventral valve are stouter and more numerous than the spinules of the dorsal valve. The ventral spines are about one-half mm. in diameter near the base, whereas the dorsal spines have scarcely one-fourth of that diameter. The shell does not have differentiated cardinal spines. In the holotype, a specimen nearly an inch in length, there is a trace of very indistinct costae at the anterior margin and near the border of the lateral slopes. The dimensions of three specimens are given below:

	Holotype	Paratype 1	Paratype 2
	mm.	mm.	mm.
Length	22	12 ±	10.7
Width	24	18.0	12.4
Convexity	9 ±	6.9	4.5+
Hinge length	17 ±	13.2	10.7

Discussion.—This species agrees rather closely with the type of *Avonia*, differing principally in the more obscure character of the costae. Of the eight specimens at hand only the largest, the holotype, shows any trace of costae; the other specimens, however, are obviously immature. This is the only recorded occurrence of *Avonia* in the American Pennsylvanian. The name is given in honor of Dr. J. Brookes Knight.

Distribution.—This species is rare in the Eudora shale of the Stanton formation in southeastern Kansas. It is not known elsewhere. The holotype was found at the center of the north side of sec. 31, T. 13 S., R. 15 E. at a railroad cut.

Genus CHONETELLA Waagen, 1887?

CHONETELLA? DUNBARI Newell, n. sp.
Plate 55, figures 5*a–c*

This little shell is transversely subquadrate, smooth and rather highly arched from front to back. The ventral valve possesses a narrow and elevated fold which slopes rather abruptly away on either side, but the fold is not bounded by sulci as in *Mesolobus*. The fold begins at the beak and exhibits a very obscure flattening along a median line at the umbo as though there had been a juvenile stage at which there was a tendency toward a ventral sulcus. The posterior margin of the ventral valve is abruptly arched into the hinge line so that the rear margin is nearly perpendicular to the general plane of the valves. The cardinal extremities are not flattened or extended but take part in the general arching of the shell. The dorsal valve is deeply concave anteriorly, becoming flattened toward the hinge and toward the extremities. A deep sulcus starting at the hinge is markedly produced at the center of the anterior margin. The cardinal margin of the ventral valve bears at least four spines on either side. These diverge outward from the hinge, the terminal ones at a low angle and the median spines apparently at a high angle. The ventral area is high and the dorsal area low, as in typical chonetids. A deltidium and chilidium are not preserved in the one specimen at hand. Unlike true chonetids the cardinal process is distinctly trifid instead of bifid, resembling in external aspect the trilobed process of *Linoproductus*. The trace of the miophores, however, is seen as shallow, obscure grooves, dividing the process into three elements, two diverging, narrow lateral elements and a prominent and broader median lobe. The shaft of the process joins the posterior margin of the dorsal valve at right angles. The slender trifid process recalls that of *Aulosteges*, but in that genus the process arches forward deep into the ventral beak, whereas the process in the present form apparently is short, and does not extend back into the ventral umbo. In typical *Chonetella* the cardinal process is trilobed and short, and is joined to the dorsal margin almost in the plane of the dorsal valve. The margin of the ventral

valve in my specimen is thickened and lamellose as though the individual were gerontic.

Discussion.—There is no chonetid genus that combines the characteristics of smooth shell and ventral fold except *Mesolobus*. The deep lateral sulci of the ventral valve which characterize *Mesolobus* are lacking in the present form, and the cardinal process is bifid in *Mesolobus* rather than trifid. Waagen's genus *Chonetella* from the Permian of the Salt Range is more like the present species than anything that has been described. The two forms are similar in the arched ventral valve, ventral lobe, cardinal spines, and a cardinal process with three rather than two elements. *Chonetella*, however, is a costate form like *Marginifera*. The relationship of *Chonetella? dunbari* to the genotype of *Chonetella* cannot be ascertained until supplementary specimens are found. The specific name is given for Dr. C. O. Dunbar, of Yale University.

Distribution.—The one specimen at hand was found in a shale just above a thin, flaggy limestone 2 miles west of Wann, Oklahoma, at a horizon tentatively correlated with the Plattsburg limestone.

Genus CHONETINA Krotow, 1888

CHONETINA PAPILIONIFORMIS Newell, n. sp.
Plate 55, figures 4*a–j*

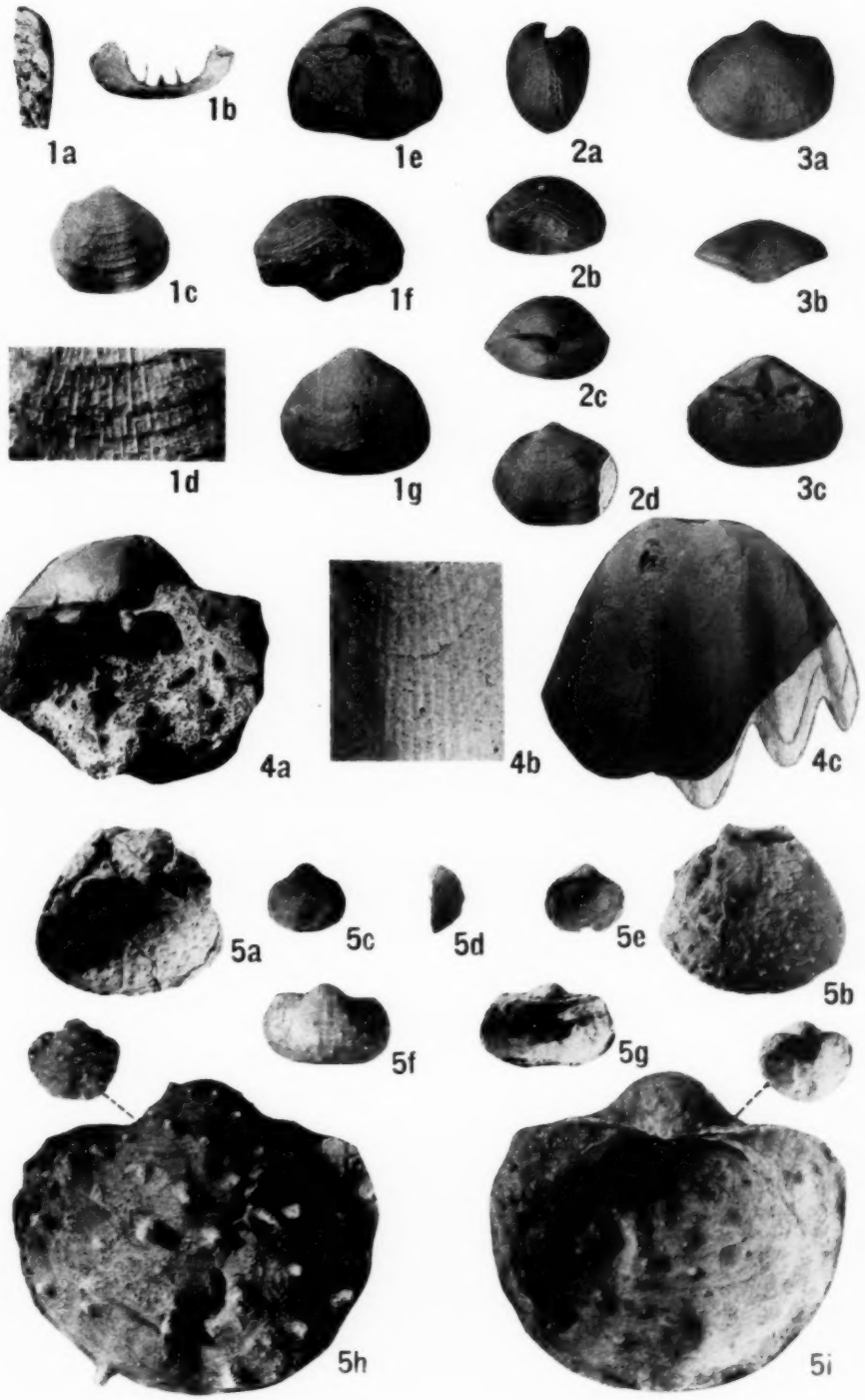
The shell is relatively small, delicate, transverse, with two narrow and steep walled folds on the ventral valve, diverging from the beak at an angle of about 34°. These ridges bound a narrow and deeply impressed median sulcus. The lateral extremities are sharply depressed from the rather steep outer walls of the lateral folds so that in extreme cases the lateral surfaces of the ventral valve outside the folds are almost flat. There are five to seven cardinal spines on either side of the beaks and the outer two or three spines are directed toward the cardinal extremities at a low angle with the hinge line. The radial lirae are spaced 5.5 to 6.6 within the space of 1 mm. In some specimens there is a small acute tip at the cardinal extremities where the angle between the hinge and the lateral margin has abruptly decreased. Commonly, however, the lateral margins are almost straight from the hinge forward nearly two-thirds the length of the shell, with the lateral margins converging forward at an angle ranging from 50 to 58°. The length of an average specimen is 5.6 mm., the width is 9.5 mm. The largest of the score or so of specimens at hand has a length of 6.6 mm. and a width of 11.4 mm. The ratio of length to width in mature specimens does not range far from 1/1.6. This description was taken from about 33 specimens. The holotype was collected from the Quindaro shale of the Wyandotte formation, at Boyn's quarry northeast of Welborne, Wyandotte County, Kansas.

EXPLANATION OF PLATE 54

FIGS. 1*a–g*, 2*a–d*, 3*a–c*—*Schizophoria texana* Girty? 1*a*, *b*, Ventral valve sectioned to show the height and form of the median ridge or "septum"; *Orthotichia* has only a slightly higher, true septum like *Enteletes*. 1*c*, An unusually narrow ventral valve. 1*d*, An enlargement, ×3 of an area in the sulcus of 1*d*. 1*e–g*, A characteristic dorsal valve. 2*a–d*, The only specimen having both valves in place. 3*a–c*, A ventral valve. Stanton, Fredonia, Kansas. (p. 425)

4*a–c*—*Parenteletes cooperi* King? *a*, Dorsal valve, showing the characteristic low cardinal area of the Schizophoriidae. *b*, Enlargement, ×5, of a part of the median sulcus of *c*. *c*, Dorsal view. Stanton formation, Fredonia, Kansas. (p. 426)

5*a–i*—*Avonia knighti* Newell, n. sp. *a–b*, The holotype, showing the characteristic ornamentation and the almost indistinguishable costae at the base of some of the spines, Eudora shale, Wilson County, Kansas. *c–e*, Juvenile topoparatype. *f–g*, A paratype. *h–i*, Paratype, ×4, same locality as *f*. (p. 426)



Newell, Pennsylvanian brachiopods

STATE OF KIOH

Discussion.—This is one of the forms that has been generally classed with *Chonetes verneuilianus* because of its deeply incised sinus. As compared with the form from northern Oklahoma which Dunbar[4] considers representative of the true *Chonetina verneuiliana* the new species is considerably smaller and more alate and markedly more depressed. From *Chonetina flemingi* and its varieties, the present form differs in details of form and especially in the peculiar arrangement of the lateral cardinal spines which, as in *C. verneuiliana*, are nearly parallel to the hinge line. Compared with *C. verneuiliana* var. *wyandottensis* these shells are thin, the ears are flat instead of arched, but they are not extended into long spine-like points.

Distribution.—The present species ranges through most of the Missouri series but is nowhere found in abundance, and is not yet known above the Lansing group. It is represented in the Quindaro and Argentine members of the Wyandotte formation, and locally in the Hickory Creek shale of the Plattsburg formation. It has been questionably identified from the Stanton formation. An examination of specimens lent by Dr. C. O. Dunbar shows that *C. papilioniformis* occurs sparingly in the Bethany Falls limestone, and more commonly in the Plattsburg limestone of the Platte Valley in Nebraska, and sparingly in the Winterset limestone of the Kansas City area.

CHONETINA VERNEUILIANA var. WYANDOTTENSIS Newell, n. var.
Plate 55, figures 3*a–g*

The shell is relatively small, transverse, alate, and massive, with a highly arched ventral valve and moderately concave dorsal valve. The median sinus of the ventral valve is narrow and rather deeply incised, corresponding to a rather prominent fold on the dorsal valve. The lateral folds of the ventral valve have precipitous slopes and diverge anteriorly at an angle of about 32°. The lateral slopes in front of the alae converge at an angle of about 40°. In lateral profile the ventral valve in undistorted specimens commonly describes nearly a complete semicircle with little tendency toward geniculation. The cardinal spines are seven or eight in number and the outer two spines of each terminus are commonly crowded together and are directed outward nearly parallel to the hinge. There are about six lirae in the space of 1 mm. across the mature portion of the shell. The lateral margins immediately in front of the extended cardinal termini are sharply concave, straightening out at a point near the mid-section before immediately becoming evenly concave across the distal ends of the lateral folds. The ratio of length to width ranges between about 1/1.4 and 1/1.7. The length of an average specimen is 6.2 mm., width, 11.7 mm. This description was formulated from about a score of specimens from the Kansas City region and from the Platte Valley in Nebraska.

Discussion.—This is one of the forms commonly referred to *Chonetes verneuilianus*. It was with hesitancy referred to *Chonetina verneuiliana* by Dunbar and Condra.[5] It seems desirable to separate the new form from the more typical representatives of the species, and to restrict *C. verneuiliana* to forms like the types and those that occur near the Avant horizon at Bartlesville, Oklahoma, and west of Ramona, Oklahoma. From the Oklahoma form the variety is distinct in its smaller size and more transverse form. The typical form of the species as contrasted with the present variety exhibits a flatter anterior slope with a slight tendency toward geniculation near the beaks and the straightened portion of the lateral margin is considerably longer than that in the variety. The typical form is considerably larger than the variety and less transverse. In spite of the small size of the variety the shells at hand are adult as shown by their exceptional thickness.

[4] Dunbar, C. O., personal communication.

[5] Dunbar, C. O., personal communication.

Distribution.—The variety is common but never abundant in various divisions of the Missouri series. It has been noted in the Winterset, Cement City, and Argentine limestones of the Kansas City region, and it is present in collections at Yale Peabody Museum from the so-called Plattsburg limestone of the Platte Valley in Nebraska. The holotype was found in the Quindaro shale at Boyn's quarry northeast of Welborne, Wyandotte County, Kansas.

Genus CHONETES Fischer, 1830–37

CHONETES GRANULIFER var. STANTONENSIS Newell, n. var.

Plate 55, figures 2*a–j*

Mature specimens of this variety are large, subquadrate, thick, and possess a shallow, though narrow sulcus on the ventral valve, extending from near the beak to the anterior margin. The dorsal valve likewise bears an obscure, narrow fold. In occasional specimens the sulcus is practically absent. The lateral margins below the hinge converge forward at an angle of about 25° or less. The cardinal extremities are small and acute. On each side of the median sinus rise broad low ridges. These diverge from each other at an angle of about 30°. The sides of these ridges or folds slope inward rather steeply toward the sulcus but the outer slopes are gently inclined in mature individuals, and somewhat steeper in juvenile individuals. The cardinal spines number eight or nine on either side of the beak. The radial lirae on the mature parts of the shell are moderately coarse, from 5 to 6.5 lirae occupying the space of 1 mm. The length of an average individual from the Stanton limestone is 12.3 mm. and the width about 18 mm. The ratio of length to width in mature individuals ranges between about 1/1.3 and 1/1.6.

Discussion.—This form has commonly been classed with typical *Chonetes granulifer* Owen. Dunbar and Condra[6] showed that the typical *C. granulifer* from the Oread formation is a large and relatively transverse form. The *C. granulifer* commonly encountered in the Missouri series is a relatively longer and more quadrate form. In the collections of brachiopods from Nebraska stored at Yale Peabody Museum the specimens from the Virgil series are perceptibly broader and more alate than the new variety. A similar form is the common Des Moines and lower Missouri *Chonetes armatus* Girty. It is, however, a distinctly smaller and thinner-shelled form than the new one.

Distribution.—The new variety has been recognized in collections from the

[6] Dunbar, C. O., and Condra, G. E., Brachiopoda of the Pennsylvanian system in Nebraska: *Nebr. Geol. Survey, Bull.* 5, p. 138, pl. 18, figs. 1–10.

EXPLANATION OF PLATE 55

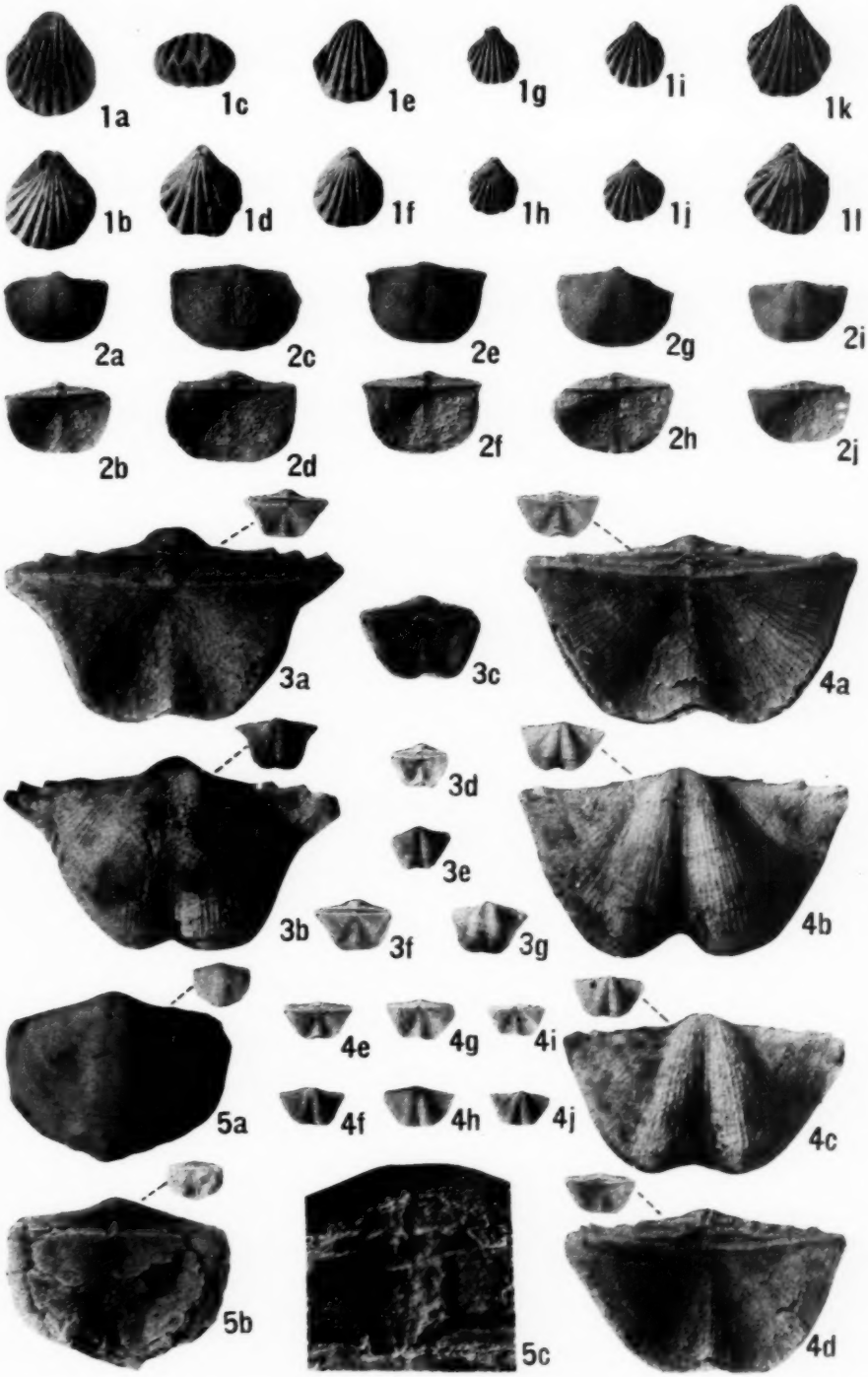
FIGS. 1*a–l*—*Hustedia acuticosta* Newell, n. sp. *a–b*, A large crushed topoparatype, Eudora shale. *c–d*, An average topoparatype, showing the circular form. *e–f*, The holotype. *g–h*, *i–j*, Juvenile topoparatypes. *k–l*, A large crushed topoparatype. (p. 431)

2*a–j*—*Chonetes granulifer* var. *stantonensis* Newell, n. var. *a–b*, *c–d*, *e–f*, *g–h*, Specimens from the Victory Junction shale near Ottawa, Kans.; *e–f* is the holotype. *i–j*, A specimen from the Little Kaw limestone near Bonner Springs. (p. 430)

3*a–g*—*Chonetina verneuiliana* var. *wyandottensis* Newell, n. var. *a–b*, Holotype, ×4, from the Argentine limestone. *c*, A paratype, ×2, from the Quindaro shale. *d–e*, Same, ×1. *f–g*, Another paratype from the same horizon. (p. 429)

4*a–j*—*Chonetina papilioniformis* Newell, n. sp. *a–b*, A paratype, ×4, from the Hickory Creek shale. *c–d*, The holotype, ×4, Quindaro shale, Wyandotte formation. *e–f*, *g–h*, *i–j*, Topoparatypes, ×1. (p. 428)

5*a–c*—*Chonetella? dunbari* Newell, n. sp. *a–b*, The only specimen, ×4, from Lansing shale near Wann, Oklahoma. *c*, Enlargement showing trifid cardinal process. (p. 427)



Newell, Pennsylvanian brachiopods

SMITHSONIAN INSTITUTION

Bethany Falls limestone 2 miles west of Oreapolis and just west of Dyson Hollow, Nebraska; from the Meadow limestone west of Meadow, Nebraska, and west of Louisville, Nebraska; from the Ladore shale at Dyson Hollow, Nebraska. In personally made collections the form is common in the Little Kaw ("South Bend") limestone and rare in the Victory Junction ("Rock Lake") shale of the Stanton formation in northeast Kansas. It has not been observed at other horizons in the upper Missouri series of eastern Kansas.

Genus COMPOSITA Brown 1849

COMPOSITA MAGNA Newell, n. sp.
Plate 53, figures 5*a–d*, 6*a–d*, 7*a–d*

The shell is large for a *Composita*, and generally triangular in specimens less than 4 cm. in length, with long straight postero-lateral margins, moderately abrupt antero-lateral shoulders, and commonly somewhat truncated anterior margins. In a few such specimens, however, the anterior margin is somewhat produced at the middle causing a resemblance to a much smaller species, *C. ovata* Mather. Specimens having a length of from 4 to 4.5 cm. and a width greater than 4 cm. may abruptly acquire a fairly well developed ventral sulcus which is produced anteriorly well beyond the remainder of the shell, and two smaller lateral sulci on the dorsal valve which rarely appear before a shell length of 2.5 cm. has been reached. The ventral sulcus extends backward as a narrow, shallow groove to within about 1 cm. of the beak but remains an obscure feature until a shell length of about 2 cm. is attained, resembling somewhat in this respect *C. ovata*. Unlike *C. ovata* or *C. subtilita*, the antero-lateral margins commonly converge forward at a large angle ranging between about 95 and 105°, whereas in the two species mentioned above the angle is generally more nearly 75°. In general appearance the present form more nearly recalls *C. trilobata* Dunbar and Condra. From that species, however, it is distinguished by the much less prominent dorsal folds on either side of the lateral sinuses. At a length of 2.5 cm. specimens of *C. trilobata* are nearly full grown with marked plications of the anterior margin, whereas in the new species at an equal size, the anterior margin of the dorsal valve is almost unmodified and the ventral sulcus is obscure. The dimensions in five undeformed specimens are:

Length	Width	Thickness
23 mm.	24 mm.	13 mm.
27	28	15
37	37	22
44	42	25
44	46	26

Discussion.—This species is associated in the Spring Hill member of the Plattsburg with *C. elongata* and *C. subtilita*. The latter species show at this horizon the normal limits of variation and are not to be confused with *C. magna*. The distinguishing features of the new species have been enumerated above but the most easily recognizable character is the large size.

Distribution.—It is common near the top of the Spring Hill member of the Plattsburg in northeastern Kansas and adjoining parts of Missouri. The holotype was collected at this horizon at the cement plant quarry, near Bonner Springs, Kansas.

Genus HUSTEDIA Hall and Clarke, 1893

HUSTEDIA ACUTICOSTA Newell, n. sp.
Plate 55, figures 1*a–l*

The shells referred to this species are relatively large, subcircular to subovate, in outline, and moderately elongate, although in many specimens the width is nearly as great as the length. The radial plications are characteristically angular. Commonly there are fourteen plications on the ventral valve and thirteen on the dorsal valve, but several specimens have only ten and nine. There seems to be a decided tendency to have fewer and larger plications than in *Hustedia mor-*

moni. The median plications of the ventral valve in some adults are slightly depressed, forming an obscure sulcus corresponding to a fold on the dorsal valve. Juvenile specimens and a few adults lack such a fold and sulcus. The length in large sized adults ranges up to 14 mm., the width, up to 12.5 mm., and the thickness to 8 or 9 mm. The width of the false area or symphytium below the foramen is commonly about one-third or more of the shell width. The dimensions in the holotype are: length, 10.7 mm., width, 9.6 mm., thickness, 7.8 mm., and the width of the symphytium 3.8 mm. The shells are punctate and have the internal structures of *Hustedia*.

Discussion.—The description is taken from about 65 specimens from a single locality. From the other Pennsylvanian species, *Hustedia mormoni*, the present form may be distinguished by its greater average size, and coarser and angular plications. The plications are rounded in *H. mormoni*. From Permian species of similar size, such as *H. meekana* (Shumard), it may be distinguished by details of form and by the number of plications.

Distribution.—The species is confined to the Eudora shale in an area south of Neosho River in Kansas. The types came from this horizon at a railroad cut at the center of the west side of sec. 36, T. 27 S., R. 16 E.

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THE GASTROPODS OF THE ST. LOUIS, MISSOURI, PENNSYLVANIAN OUTLIER: VIII. THE TURRITELLIDAE

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ABSTRACT

This paper treats primarily the American Pennsylvanian species of the genus *Orthonema* Meek and Worthen, which is restudied and emended. The family relationships are discussed and it is suggested that *Orthonema* is a representative of the stock from which *Turritella* was derived. It is referred to the Turritellidae together with the closely related genus *Acanthonema* Grabau. The previously described species of *Orthonema* are redescribed and refigured from their types or from topotype material and five new species are described and figured. These new species are *Orthonema inornatum*, *O. werneri*, *O. schucherti*, *O. sayrei*, and *O. marvinwelleri*. A new sinistral species of *Murchisonia*, *M. sinistrorsa*, is described from among the syntypes of *O. liratum* Sayre. A key to the American Pennsylvanian species of *Orthonema* is given.

In an appendix the new name *Haticopsis wortheniana* is proposed to replace *Haticopsis wortheni* Knight, preoccupied.

A revision of the correlations of the St. Louis Pennsylvanian outlier in the light of recent knowledge is presented.

This paper is the eighth of a series dealing with the gastropods of the American Pennsylvanian, principally as represented in collections from the outlier at St. Louis, Missouri (1). As with the two preceding papers, however, the scope is extended to include material from other localities and from horizons not represented at St. Louis. I am indebted to several individuals and institutions for the loan of types of previously described species and for topotype material without which some of the older species would be difficult to understand. To Dr. J. Marvin Weller of the Illinois State Geological Survey, Prof. T. E. Savage of the University of Illinois, and to Prof. Raymond C. Moore of the Kansas Geological Survey, I am particularly under obligations. Thanks for laboratory and office facilities are also due authorities of Occidental College, Los Angeles, where this paper was prepared.

Localities in the St. Louis outlier are given by number, for the key to which the reader is referred to a previous paper (4, pp. 175–178) where they are listed in detail. Localities in other areas are described here as accurately as my information permits.

CORRELATIONS

Increased knowledge of the stratigraphy of the Pennsylvanian in western Missouri, due principally to the great number of wells drilled for gas and oil, has made necessary some changes in previous grouping of the stratigraphic units in that region. These changes have been set forth briefly in a recent publication by Dr. F. C. Greene (2, pp. 12–19). Since the

correlations of the stratigraphic units in the St. Louis outlier were made on the basis of the central and western Missouri section as previously worked out by Hinds and Greene (3), these correlations will accordingly need some revisions as well. In general, the revisions in western Missouri have to do with the identifications of the coal horizons, and their precise placement within the lithologic units. Thus, the Lexington coal is found to be in the lower half of the Labette shale instead of at the top of the Cherokee shale, the Summit coal lies between the two limestone members of the Fort Scott and the coal at the top of the Cherokee just beneath the lower Fort Scott limestone is the Mulky. Greene also points out and describes for the first time a rather persistent limestone in the Labette shale which as yet bears no formal name, the "Brown lime" of the drillers. The Henrietta formation thus includes four persistent limestone members instead of three.

Viewing the section exposed in the St. Louis outlier in the light of these revisions gives the results shown in the following tabulation.

From the above it will be evident that since most of the gastropods of the St. Louis outlier were found in Cycle E in the upper Labette shale just below the Pawnee limestone, the re-correlations will affect the stated stratigraphic occurrence of only a relatively few species and at the most by one cycle only. Furthermore, rather than introduce an element of confusion into this series of papers by using different correlations in the later papers than in the earlier ones,

Saint Louis Outlier (Key Beds)			Illinois section in Cyclothems (Wanless and Weller, 5)
As previously correlated (Knight, 1*a*, p. 5; 4, p. 45)	Cycles Knight 4	As now revised	
Unnamed sandstone	G	Warrensburg (?) sandstone	? ? ?
	F		Gimlet cyclothem
Pawnee limestone	E	Pawnee limestone	Sparland cyclothem (Piasa limestone)
Upper Fort Scott limestone	D	So-called "Brown lime" in the Labette shale.	Brereton cyclothem
Middle Fort Scott coal		Lexington coal	(No. 6 Coal)
Lower Fort Scott limestone	C	Upper Fort Scott limestone	St. David cyclothem
Lexington coal		Summit coal	(No. 5 Coal)
"Chaetetes" limestone	B	Lower Fort Scott limestone	Summum cyclothem
Summit (?) coal		Mulky coal	(No. 4 Coal)
Bevier coal	A	Bevier coal	Liverpool cyclothem (Colchester No. 2 Coal)

the original correlations will be adhered to until a final summary is reached. Nevertheless, since some time may elapse until the final summary and survey of the fauna can be made, it seems best to include at this time a notice of the changes in correlation suggested by Greene's publication of his revisions of the Western Missouri section.

It may be noted that the correlations suggested above eliminate some of the difficulties encountered in the earlier correlations, such as the supposedly missing cycle in the St. Louis section (4, p. 170).

GENUS *ORTHONEMA*

The genus *Orthonema* was established by Meek and Worthen in 1861 (6, p. 146) with *Eunema? salteri* Meek and Worthen, 1860, as genotype by original designation. As the name suggests, these authors were particularly impressed with the nearly straight outer lip of the gastropod. The oramentation, consisting of revolving carinae, was considered as of importance, but seems to have impressed them less than the character of the outer lip as shown in the growth-lines. At that time only the one species was referred to the genus. A second species, *O. conicum*, was described and referred to the genus in 1866 by these same authors, but the value of their description and understanding of the species was impaired by the poor state of preservation of the holotype, which I have before me. I also have several better preserved specimens from the same horizon in the same region as the type locality loaned me by Dr. J. M. Weller. Thus, they failed to note, among other things, that in this species the outer lip is not straight but is slightly sinuous and in a fashion which is seemingly unique in Paleozoic gastropods. Since 1866, three other species have been described and a fourth, originally described by Geinitz as *Murchisonia*, has been referred to the genus. These, together with the five new species described herein, will serve to better characterize the genus which may be described as follows.

Generic Description.—Small, many whorled, high-spired, anomphalous gastropods with a sharp, nearly straight to moderately sinuous outer lip, and a slightly arcuate, moderately reflexed inner lip. The ornamentation consists of revolving angulations, ridges or carinae typically arranged in two groups with a wide band between, this band being either free from ornamentation or with very fine revolving threads and growth-lines only. The sinuosity of outer lip is distinctive, especially when strongly developed. When strongly developed, the growth-lines pass rather sharply backward from the upper suture with a curvature distinctly convex toward the aperture; in passing across the upper zone of revolving ornamentation they curve sharply downward, pass across the face of the whorl-face with a slight concavity toward the aperture and finally across the base with a slight convexity in the same direction. Where the sinus is weakly developed, the course of the growth-

lines may be nearly straight. The revolving ornamentation is in some species more strongly developed than in others and in general the stronger the development of this ornamentation, the more nearly straight and less sinuous the outer lip. The nuclear whorls are simple and dextal. The shell is composed of two primary layers, though the inner one which makes up the bulk of the shell seems not to have been nacreous. As the shell grew, the inner walls of the earlier whorls are at first covered with secondary deposits which form a third shell layer and are finally partitioned off by transverse septae, concave toward the aperture. This last character has been seen in thin sections of specimens of *O. salteri* and *O. inornatum*.

Taxonomic Position.—Meek and Worthen, when describing *Eunema* (?) *salteri*, the genotype of *Orthonema*, and when proposing the genus, were seemingly much struck with the similarity of that species to those shells which form the well-known Mesozoic to Recent genus *Turritella*. *Orthonema salteri* even with its relatively straight outer lip does certainly remind one strongly of *Turritella*, but the suggestion of relationship is greatly re-enforced by the form of the outer lip in *O. conicum* and *O. inornatum*, n.sp., in which the characteristic sinuosity is much more strongly developed and on a pattern quite similar to the characteristic one in *Turritella*. This new information, coupled with the general form of the spire, the ornamentation as well as other apertural characters, seem to compel the inclusion of *Orthonema* in the Turritellidae. *Orthonema* would carry with it into the Turritellidae the seemingly closely related genus *Acanthonema* Grabau.

Orthonema approaches several families of high-spired Paleozoic gastropods rather closely in one or more particulars. Thus, it shares with the Loxonematidae its high spire, slightly arcuate columella, reflexed inner and somewhat sinuate outer lip; but differs in the possession of characteristic revolving ornamentation and in the peculiar form of the sinus when well developed. From the Streptacididae it differs in the form of the sinus, but most particularly in its normal nuclear whorls. From the Murchisoniidae it differs in lacking a lunulate band as well as in the shape of the sinus. The less ornamented species suggest the Pseudomelaniidae, but are barred from placement there by the sinus which is best developed in those forms with least ornamentation. *Orthonema* is regarded as standing midway between the Murchisoniidae and Loxonematidae, and as having been derived from the former.

Orthonema is known at present only from the Pennsylvanian of North America. Doctors J. W. Beede and G. H. Girty have described several species from the Permian of the western states that are referred to *Orthonema* by their authors. These species, however, are inadequately known from rather poor material and I shall not treat them here. Moreover, they show certain differ-

ences that suggest that they represent a new generic type.

American Pennsylvanian Species.— Prior to this study, a total of six species have been described, all of which seem to be distinct and all, with the possible exception of *O. subtaeniatum*, valid members of the genus. These species are: *Orthonema salteri* (Meek and Worthen), 1860; *O. conicum* Meek and Worthen, 1866; *O. subtaeniatum* (Geinitz), 1866; *O. carbonarium* Worthen, 1884; *O. bilineatum* Mark, 1912; *O. liratum* Sayre, 1930. I have before me the holotypes of *O. salteri*, *O. conicum*, *O. bilineatum* and *O. liratum*. I have a chorotype[1] of *O. carbonarium*, collected and identified by Dr. J. M. Weller. The holotype of *Murchisonia subtaeniatum* Geinitz is supposedly in the Marcou collection at Harvard, but I have failed to find it although I have searched through that collection. Still it is a tiny specimen and may easily have been overlooked. This last species is the only one of which the characters may not be definitely ascertained, since neither Geinitz's original description or figures (7, p. 12) or Meek's subsequent ones (8, p. 228) characterize the species sufficiently well. Whether Mark's plesiotype (10, p. 316, pl. 16, fig. 3) is properly identified I do not know. All of the above species except *O. subtaeniatum* are redescribed and refigured here and five new species described.

[1] A fossil specimen collected from the same stratum as the type, but from a neighboring locality. The term was introduced by Buckman in 1920. See Frizzell, *Am. Midland Naturalist*, vol. 14, p. 646, 1933.

It seems worthy of note that specimens of species of *Orthonema* are relatively rare. Thus, from the top of the Labette shale at Loc. 43 in the St. Louis outlier, only five specimens of a single species of *Orthonema* were found, while species of other genera are commonly represented at the same horizon and locality by many, in some cases by hundreds, of specimens. With the exception of *O. salteri*, which is represented in the collections of the Illinois State Geological Survey by about thirty specimens, all the known species are represented by a very few specimens only, even though the localities where they were found were collected intensively and commonly yielded many specimens of species of other genera. The rarity of specimens of species of *Orthonema* detracts from their value as guide-fossils. Indeed, with the possible exceptions of *O. salteri* and *O. ? subtaeniatum*, all of the known species are recorded from small collections at a single horizon and locality. It is to be hoped that further intensive collecting will remedy this situation to some extent.

The specimens on which this study has been based are to be found in the various depositories cited under each. Scarcity of specimens has made it impossible for me to distribute additional material from my own collections among other institutions.

KEY TO THE SPECIES OF *ORTHONEMA* HERE DESCRIBED

The revolving carinae that lie just below the upper suture are called "superior"; those just above the lower suture or on the base below it, "inferior." Superior and inferior cari-

nae always widely separated by flat, central whorl-face.

A_1 Revolving carinae very weak; sinus relatively well-developed.

B_1 A single, superior carina; two inferior carinae, extremely faint, or wanting; spire slender, relatively numerous whorls..... *O. inornatum* (p. 446)

B_2 A single superior carina; a single inferior carina, not covered; spire relatively short, with convex sides..... *O. conicum* (p. 445)

A_2 Revolving carinae moderately developed; sinus weakly developed; two inferior carinae, the lower one on the base and covered by the succeeding whorl.

B_3 A single superior carina; growth-lines weak; no revolving threads on whorl-face, shell relatively small.. ..... *O. werneri* (p. 441)

B_4 Two superior carinae, crowded together; growth-lines coarse; faint revolving threads on whorl-face; shell relatively large..... *O. schucherti* (p. 441)

B_5 Two superior carinae, not crowded; growth-lines coarse; faint revolving threads on whorl-face; shell relatively small ..... *O. bilineatum* (p. 440)

B_6 Two superior carinae, not crowded: carinae rather weak; growth-lines faint; no revolving threads on whorl-face; shell relatively small.. ..... *O. sayrei* (p. 439)

B_7 Two superior carinae, not crowded; carinae well developed; growth-lines strong; no revolving threads on whorl-face; shell relatively large ..... *O. salteri* (p. 438)

A_3 Revolving carinae moderately to strongly developed; sinus weakly developed; inferior carinae (one or two) on whorl-face, above lower suture, none on base.

B_8 A single superior carina; two inferior carinae; carinae moderately developed; shell relatively small; base rounded.. *O. liratum* (p. 443)

B_9 Two superior carinae, and two inferior carinae, both pairs strongly developed; shell relatively small; base flattened..... *O. marvinwelleri* (p. 445)

B_{10} One superior and one inferior carina, moderately well-developed, a shallow groove on the inner side of each; shell relatively large, base flattened.. *O. carbonarium* (p. 442)

O.? subtaeniatum (Geinitz) is omitted from the above key.

DESCRIPTION OF SPECIES

Family TURRITELLIDAE Gray

Genus ORTHONEMA Meek and Worthen, 1861

ORTHONEMA SALTERI Meek and Worthen

Plate 56, figures 1*a–d*

Eunema? salteri MEEK and WORTHEN, *1860*, Acad. Nat. Sci., Philadelphia, Proc., p. 464.

Orthonema salteri MEEK and WORTHEN, *1866*, Illinois Geol. Survey, vol. 2, p. 381, pl. 31, figs. 14*a–c*. Lower Coal Measures (St. David limestone[2]), Hodges Creek, Macoupin County, Illinois.

Measurements of *Orthonema salteri*

	A	B
Number of whorls	13[a]	12½[a]
Height	12.25 mm.	11.7 mm.
Width	4.25 mm.	3.7 mm.
Ratio height to width	2.9	3.15
Ratio of height of body whorl to total	0.17	0.22
Pleural angle	15°	13°

A. The holotype, a mature individual (Pl. 56, figs. 1*a–b*).

B. A paratype (not figured.)

[a] Based on the assumption that two apical whorls are missing.

[2] Oral communication from Dr. J. M. Weller.

Small, high-spired, turreted gastropods with gently convex sides; whorl profile strongly shouldered at the two subsutural revolving carinae, flat and vertical on the sides, giving the whorls a drum-like appearance, angulated at the upper prominent one of the two lower revolving carinae, and gently rounded on the base; sutures shallow; columella very slightly arcuate; columellar lip reflexed; parietal inductura very thin, inconspicuous; outer lip as shown by the growth-lines nearly straight, passing from the upper suture to the upper carinate zone with a very slight but distinctly recognizable obliquity away from the aperture, continuing across the flat face of the whorl, vertically down and across the prominent lower carina, and curving very gently backward on the base to the columella; ornamentation, four moderately strong revolving carinae arranged in upper and lower pairs, the inner member of each pair being the more prominent; the upper-

most carina a slight distance below the upper suture and separated from the second by a concave band only slightly wider than the band between it and the suture; the third carina, the upper one of the lower pair lying just above the lower suture and equal in development to the lower one of the upper pair; the fourth carina weakly developed, a mere angulation, lying on the base well below the prominent angulation at the third carina and covered by succeeding whorls, a circumcolumellar raised area within it; color pattern, shown on two chorotypes, a dark revolving band between the two upper carinae and a second one on the base just below the third carina, on one specimen the dark bands showing a wine-red color against a gray background. I have before me Meek and Worthen's collection (Univ. of Illinois, No. 11031) consisting of the holotype (the specimen figured by Meek and Worthen) and three paratypes. These were collected from the St. David limestone on Hodges Creek, Macoupin County, Illinois.[3] I also have a chorotype collection of thirty specimens belonging to the Illinois Geological Survey (No. 193) and collected by Dr. J. M. Weller from the same horizon in N. center, sec. 30, T. 11 N., R. 10 W., Greene County, Illinois. One specimen, probably referable to this species, was found in the type collection of *Murchisonia copei* White (U. S. Nat. Mus., No. 8927) from near Taos, New Mexico. Although the St. David limestone ("lower Fort Scott" limestone of this series of papers) in the St. Louis outlier has yielded some gastropod material, only one specimen of *Orthonema* was found and it is too poorly preserved to be identified.

[3] Meek and Worthen in their original description of *O. salteri* give the horizon and locality as "Upper Coal Measures, Springfield, Illinois," but this seems to have been a slip of the pen since only the Hodges Creek locality is cited in the second and presumably corrected citation in volume 2 of the Illinois Survey. Furthermore, not only are the labelled types marked as from Hodges Creek, but they carry the type of preservation characteristic of that locality. The species is known to be abundant there, but has not otherwise been reported from Springfield.

ORTHONEMA SAYREI Knight, n. sp.
Plate 56, figure 3

Orthonema liratum SAYRE (*pars*), *1930*, Kansas Geol. Survey, Bull. 17, p. 151, but not pl. 17, figs. 2–3, Westerville limestone, Pennsylvanian, Muncie, Kansas.

Measurements of *Orthonema sayrei* Knight

	A
Number of whorls	14[a]
Height	8.0 mm.[a]
Width	2.6 mm.
Ratio of height to width	3.07
Ratio of height of body whorl to total	0.33
Pleural angle	13°

A. The holotype (Pl. 56, fig. 3).

[a] Estimated on the assumption that two apical whorls are missing.

Small, high-spired, slightly turreted gastropods with sides straight at ephebic and convex at neanic stages; whorl profile moderately shouldered at the two subsutural revolving carinae, flat to gently arched on the sides, gently angulated at the upper of the two lower revolving carinae, and rounded on the base; sutures shallow; outer lip, as shown by the growth-lines, nearly straight, very shallowly concave toward the aperture; ornamentation four low observed revolving carinae arranged in upper and lower pairs, the inner member of each pair being the more prominent; the uppermost carina a slight distance below the upper suture and separated from the second by a concave band at least twice as wide as the band between it and the suture; the third carina, the upper one of the lower pair lying just above the lower suture and weaker in development than the lower one of the upper pair; the fourth carina weakly developed, lying on the base well below the line of suture; a circumcolumellar raised area within it; the lines of growth very obscure; color pattern unknown.

Sayre's collection of *O. liratum* con-

sisted of four syntypes, here placed in two families and in three species. *O. sayrei* has for its holotype one of the original syntypes of *O. liratum*. *O. sayrei* is very close indeed to *O. salteri*, differing principally in its considerably smaller size and in general less well-developed salient features. Thus, the revolving ornamentation and shouldering of the whorls are relatively weaker than in *O. salteri* and the junction of the whorl-face with the base is rounder and less angulated. Also, the form is narrower and less robust. The upper revolving carina is relatively closer to the suture. Specimens placed side by side show marked differences that are difficult to express in words. *O. sayrei* might well be regarded as a mutant of *O. salteri* or, what would be more difficult to prove, an ecad, a member of a dwarfed fauna such as has been attributed to the supposedly unfavorable conditions prevailing during the deposition of the oolitic Westerville limestone. However, since any conclusive evidence of either is wanting, I prefer to regard it as a distinct, though closely related species. The holotype and only specimen is from the Westerville limestone at Muncie, Kansas. It is in the University of Kansas collection.

ORTHONEMA BILINEATUM Mark

Plate 56, figure 2

Orthonema bilineatum MARK, *1912*, in Condit, Conemaugh formation in Ohio, Ohio Geol. Survey, Bull. 17, p. 316, pl. 16, fig. 14. Ames limestone, Conemaugh formation, New Concord, Ohio.

The specimen is too imperfect to warrant any measurements.

Small, high-spired, turreted gastropods, probably with gently convex sides; whorl profile gently convex and only moderately shouldered at the two subsutural carinae; base and aperture unknown, except as the outer lip is shown by growth-lines on the whorl-face; outer lip with a wide, very shallow sinus, the growth-lines passing downwards and backwards from the upper suture across the two visible revolving carinae, slightly convex toward the aperture and then gradually curving downward, concave forward to aperture, until they have a slight forward component where they disappear beneath the following whorl; growth-lines sharp striae; known revolving ornamentation, two carinae a short distance below the upper suture, the upper, and somewhat stronger one about equidistant from the suture and the second carina; the upper of the (probably) two lower carinae barely

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EXPLANATION OF PLATE 56

FIGS. 1*a–d*—*Orthonema salteri* (Meek and Worthen). All figures ×4. *a–b*, The holotype (Univ. of Ill., No. 11031). *c*, A chorotype in the collection of Illinois State Geological Survey, photographed to show color pattern. *d*, A plesiotype from New Mexico in the U. S. Nat. Mus. (p. 438)

2—*Orthonema bilineatum* Mark. The holotype (Univ. of Ohio, No. 14053), ×5. (p. 440)

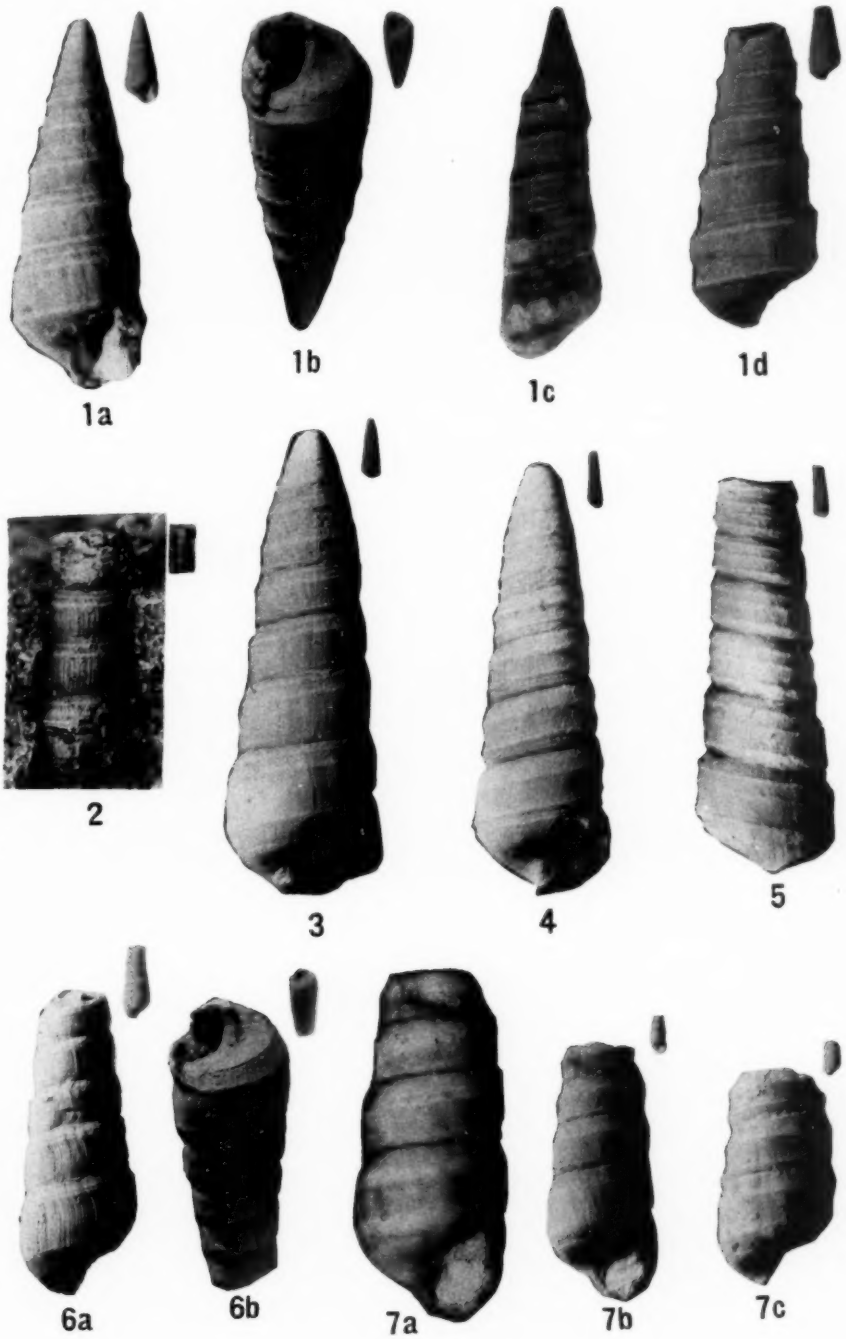
3—*Orthonema sayrei* Knight, n. sp. The holotype (Univ. of Kansas collection), ×8. (p. 439)

4—*Orthonema liratum* Sayre. The holotype, here designated (Univ. of Kansas collection), ×8. (p. 443)

5—*Murchisonia sinistrorsa* Knight, n. sp. The holotype (Univ. of Kansas collection), ×8. This is one of the originally figured syntypes of *O. liratum* Sayre. (p. 444)

6*a, b*—*Orthonema schucherti* Knight, n. sp. The holotype (Yale Univ., Peabody Mus., No. 13940), ×4. Figure 6*b* shows the aperture (somewhat badly broken) and the slightly raised area that surrounds the columella below the lowermost carina. (p. 441)

7*a–c*—*Orthonema werneri* Knight, n. sp. *a–b*, The holotype (Yale Univ., Peabody Mus., No. 13942). *a*, Photographed to show the color-pattern (×8). *b*, With a coating of ammonium chloride, to show ornamentation (×6). *c*, A paratype (×6). (Yale Univ., Peabody Mus., No. 13943.) (p. 441)



Knight, Pennsylvanian gastropods

visible above the lower suture, the lowest not seen; several very faint revolving threads on the whorl-face; coloration unknown.

This species is known only from the holotype, a fragment of four ephebic whorls deeply embedded in matrix and with the base of the last whorl chipped away. While it is unfortunate that the species is founded on such inadequate material, *O. bilineatum*, although very close to *O. salteri*, seems to be distinguishable from that and all other known species. It differs from *O. salteri* in that the upper of the two upper revolving carinae is a little the stronger, that the upper of the two lower carinae barely shows above the suture, in the possession of faint, revolving threads on the whorl-face, in the rather strong growth-lines and in the slight convexity of the whorl-face. It is closer to *O. schucherti* and differs principally in the relatively wide spacing of the two upper revolving carinae, which in that species are weaker and much closer together, and in its smaller size.

The holotype, from the Ames limestone at New Concord, Ohio, is the only known specimen. It bears University of Ohio number 14053.

ORTHONEMA SCHUCHERTI Knight, n. sp.
Plate 56, figures 6*a–b*

Measurements of *Orthonema schucherti*

	A	B
Number of whorls	—[a]	—[a]
Height	10 mm.[b]	13 mm.[c]
Width	3.9 mm.	4.7 mm.
Ratio of height to width	—[a]	—[a]
Ratio of height of body whorl to total	—[a]	—[a]
Pleural angle	12°	11°

A. The larger of my two specimens (not figured).

B. The holotype (Pl. 56, fig. 6*a–b*).

[a] No specimen sufficiently complete to make any reasonably secure estimate.
[b] Measured on the last five whorls only.
[c] Measured on the last five and one-half whorls only.

Moderately small, high-spired, turreted gastropods with straight sides; whorl profile moderately shouldered at the top, closely spaced, subsutural revolving carinae, gently arched on the sides, very slightly angulated at each of the two lower revolving carinae, the base otherwise being rounded; sutures shallow; columella very slightly arcuate, columellar lip reflexed; parietal inductura thin; outer lip, as shown by rather coarse growth-lines with a broad shallow sinus, the growth-lines being slightly convex toward the aperture above the upper carinae and on the base, concave toward the aperture on the whorl-face; ornamentation, four rather weak, low, revolving carinae of which the two uppermost are so close together as to appear to be one except on careful examination, the distance of the uppermost from the upper suture being three or four times that between it and the second carina; the uppermost of the two lower carinae barely covered by the next succeeding whorl and only to be seen on the base; the lowermost carina on the base well below the line of the suture, and with a circumcolumellar raised area within it; several very faint revolving threads on the whorl-face; color pattern unknown.

O. schucherti is very close to *O. bilineatum*, but is larger and the two upper carinae are very much closer together. *O. werneri* is smaller, has finer lines of growth, shows the upper of the two lower carinae clearly above the lower suture and either there is one upper carina or the two typically present have coalesced into one.

I have two specimens of this species, both collected by Prof. Charles Schuchert from the Jacksboro limestone of the Cisco formation, 10½ miles east of Graham, Texas. These bear Yale Peabody Museum Nos. 13940 (the holotype) and 13941.

ORTHONEMA WERNERI Knight, n. sp.
Plate 56, figures 7*a–c*

Measurements of *Orthonema werneri*

	A	B	C
Number of whorls	—[a]	—[a]	—[a]
Height	6.0 mm.[b]	—[a]	—[a]

	A	B	C
Width	2.4 mm.	2.6 mm.	2.3 mm.
Ratio of height to width	—[a]	—[a]	—[a]
Ratio of height of body whorl to total	—[a]	—[a]	—[a]
Pleural angle	12°	11°	12°

A. The holotype (Pl. 56, fig. 7*a–b*).
B. A paratype (Pl. 56, fig. 7*c*).
C. A paratype (not figured).

[a] No specimen sufficiently complete to make any reasonably secure estimate.
[b] Measured on the last five whorls only.

Small, high-spired, turreted, gastropods with straight sides; whorl profile moderately shouldered at the single subsutural carina, flat to slightly concave on ephebic whorls between the upper carina and the upper one of the lower two carinae, sharply, though shallowly re-entrant just above the lower suture; columellar lip reflexed; parietal inductura thin; outer lip nearly straight; ornamentation on ephebic whorls, three moderately elevated, revolving carinae becoming obsolete at gerontic states; a single subsutural carina about two-fifths the suture-to-suture distance below the upper suture with a faint suggestion on some specimens of another carina close above it or coalesced with it; another revolving carina distinctly above the lower suture and a third much weaker one on the base below the line of suture; color pattern three dark revolving bands, one above the uppermost carina, another around the intracarinal whorl-face, and a third on the base between the two lower carinae, the slightly raised columellar region below the lowest carina being light-colored.

O. werneri is smaller than other similar species of *Orthonema*, with the possible exception of *O. bilineatum* and of *O. sayrei*. It is distinguished by its single subsutural carina and its exposed upper of the two lower carinae bounding a flat to slightly concave whorl-face. It is perhaps closest to *O. carbonarium*, from which it differs in its much smaller size, rounder base and simple median whorl profile. The name is in honor of Prof. W. Courtney Werner of Washington University, St. Louis, who helped me collect from the locality where these specimens were found.

I have but three specimens, all consisting of only the last three to five whorls, and all from the base of the Pawnee limestone at Loc. 6 in the St. Louis outlier. The holotype bears Yale Peabody Museum No. 13942, the paratypes No. 13943.

ORTHONEMA CARBONARIUM Worthen
Plate 57, figure 4

Orthonema carbonaria WORTHEN, *1884*, Illinois State Mus. Nat. Hist., Bull. 2, p. 7. Coal Measures (Lonsdale limestone[4]), Peoria County, Illinois.

Orthonema carbonarium WORTHEN, *1890*, Illinois Geol. Survey, vol. 8, p. 145, pl. 24, figs. 4, 4*a*. (Re-publication of original description with figures.)

Measurements of *Orthonema carbonarium*

	A
Number of whorls	17[a]
Height	11 mm.[b]
Width	5.15 mm.
Ratio of height to width	—[c]
Ratio of height of body whorl to total	—[c]
Pleural angle	12°

A. A chorotype (Pl. 57, fig. 4).

[a] Estimated from two very imperfect chorotype specimens.
[b] The height of the last four whorls only.
[c] No specimens sufficiently complete to make an estimate of total height.

Moderately small, high-spired, only slightly turreted gastropods, with straight sides; whorl profile only moderately shouldered at the single subsutural carina, rather flat between the upper (subsutural) and lower carinae, except that just within each carina there is a distinct concavity; sharply angulated at the lower carina and with a nearly flat base; sutures shallow; apertural and columellar characters unknown, though thought to be in accord with those of the genus; ornamentation two moderately elevated revolving carinae, the upper separated from the upper suture by a narrow sloping area and the lower

[4] Oral communication, Dr. J. M. Weller.

just above the lower suture, within each carina a narrow, shallow revolving groove bordering the flattened area between; color pattern unknown.

This species is characterized by its size, and particularly by the revolving grooves just within the two prominent carinae on the whorl-face, and by its markedly flattened base. In the last character, it is similar to *O. marvin-welleri*, but that species is smaller and shows four strong revolving carinae and no grooves.

O. carbonarium is known only from its rather imperfect holotype, supposed to be in the Illinois State Museum, but which I have been unable to examine, and the three rather imperfect chorotypes loaned me by Dr. J. M. Weller of the Illinois State Geological Survey. The best of these chorotypes is figured herein. Yet the species seems to be well characterized by the features described above. The three chorotypes were collected by Weller from the Lonsdale limestone in the NW. ¼, sec. 34, T. 8 N., R. 6 E., Peoria County, Illinois. They are in the collection of the State Geological Survey and bear No. 1418.

ORTHONEMA LIRATUM Sayre
Plate 56, figure 4

Orthonema liratum SAYRE (*pars*), *1930*, Kansas Geol. Survey, Bull. 17, p. 151, but not pl. 17, figs. 2–3. Westerville limestone, Pennsylvanian, Muncie, Kansas.

Measurements of *Orthonema liratum*

	A
Number of whorls	12[a]
Height	7.4 mm.
Width	2.5 mm.
Ratio of height to width	2.95
Ratio of height of body whorl to total	0.35
Pleural angle	12°

A. The holotype (Pl. 56, fig. 4).

[a] Estimated on the assumption that two apical whorls are missing.

Small, high-spired, very slightly turreted gastropods, with sides straight at ephebic and convex at neanic stages; whorl profile convexly shouldered above the upper revolving carina, gently concave on the whorl-face between the upper carina and the lower pair, gently rounded on the base without a pronounced angulation at the lower pair of carinae; columella slightly arcuate; inner lip slightly reflexed; parietal inductura thin and inconspicuous; outer lip unknown; ornamentation, three weak revolving carinae, the single upper one of the lower pair the stronger; the upper carina separated from the upper suture by a convex, outward-sloping area a little over half as wide as the concave band on the whorl-face; the two lower carinae closely spaced, both showing above the lower suture and with traces of a faint revolving thread in the area between them; lines of growth very obscure; color pattern unknown.

O. liratum, as here emended, is quite distinct in the possession of three revolving carinae, one above, separated from the upper suture by a convex area and two below, closely spaced and just above the lower suture.

Through the courtesy of Prof. R. C. Moore, I have before me the four syntypes (so labelled) on which Sayre based his species. He designated no holotype. These syntypes include the two sinistral specimens figured by Sayre (9, pl. 17, figs. 2–3) which on close examination are found to have a deep sinus in the outer lip and a selenizone[5] between the two carinae on the upper part of the whorl-face. These specimens are then Murchisonids. In addition, the labelled syntypes include two dextral specimens not figured by Sayre, one of which is here designated the holotype of *O. liratum* Sayre (See Pl. 56, fig. 3), while the new species, *O. sayrei*, is founded on the second. I should have greatly preferred designat-

[5] The term selenizone (Greek σελήνις =crescent, and ζώνη=belt, girdle) is introduced to replace "slit-band" and "band of the sinus." It will be discussed more in detail in forthcoming papers dealing with the Murchisoniidae, Pleurotomariidae and Bellerophontidae.

ing the larger of the two sinistral specimens figured by Sayre as holotype, but since they are Murchisonids, such action would have brought the name into conflict with *Murchisonia lirata* (Ulrich) Miller, 1897, and possibly required its suppression as an homonym.

Since the specimens figured by Sayre (Loc. cit.) are thus left nameless, I propose for them the name *Murchisonia sinistrorsa* Knight, n.sp., and designate the larger of the two specimens figured by Sayre (Loc. cit., fig. 3) as the holotype. A photograph of this specimen is included on Plate 56 of this paper, and for sake of nomenclatural technicalities a brief description is given below in a footnote.[6] It should be unnecessary to point out that the reviser of a species is not confined in his choice of a holotype to figured syntypes (often, but without warrant, called "type figures") although it is commonly good practice to select a holotype from such a figured syntype. In this case it seems inadvisable to do so for the reasons stated.

[6] *Murchisonia sinistrorsa* Knight, n. sp. Small, high-spired, flat-whorled and flat-sided, sinistral gastropods, with a deep sinus culminating in a selenizone bounded by two carinae, a little above the middle of the whorl-face; two additional revolving carinae at the angulation of the base, one passing above and the other just below the line of suture; sutures groove-like. Holotype and paratype, from the Westerville limestone at Muncie, Kansas, in the University of Kansas collections.

The specimen selected as holotype of *O. liratum* Sayre is from the Westerville limestone at Muncie, Kansas, and is deposited in collections at the University of Kansas.

ORTHONEMA MARVINWELLERI Knight, n. sp.
Plate 57, figures 3*a–c*

Measurements of *Orthonema marvinwelleri*

	A	B	C
Number of whorls	—[a]	—[a]	—[a]
Height	7.1 mm.[b]	6 mm.[c]	4.7 mm.[b]
Width	4.1 mm.	3 mm.	2.7 mm.
Ratio of height to width	—[a]	—[a]	—[a]
Ratio of height of body whorl to total	—[a]	—[a]	—[a]
Pleural angle	13°	12°	11°

A. The largest specimen, a paratype (Pl. 57, fig. 3*b*).
B. The holotype (Pl. 57, fig. 3*a*).
C. A paratype (Pl. 57, fig. 3*c*).

[a] Material too imperfect to make a satisfactory estimate.
[b] Four final whorls.
[c] Five final whorls.

Small, high-spired, only slightly turreted gastropods with straight sides; whorl-profile slightly shouldered in the region of the two subsutural carinae, which have a narrow concave band between them, concave to nearly flat on the whorl-face between the two median carinae, concave between the two lower carinae, sharply angulated at the lowest, and with a markedly flat base; sutures shallow; columellar and outer lips poorly preserved on the type specimens, but

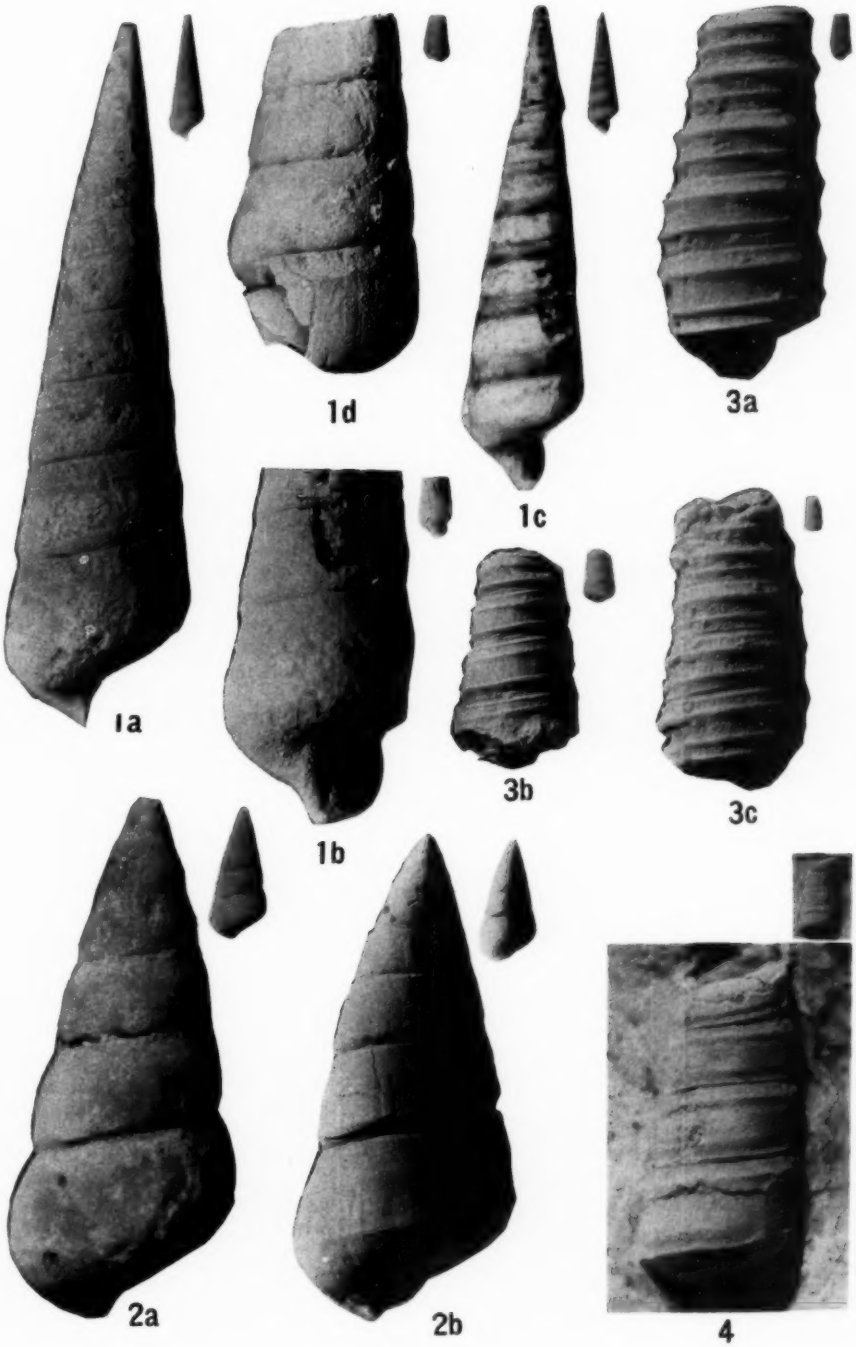
EXPLANATION OF PLATE 57

FIGS. 1*a–d*—*Orthonema inornatum* Knight, n. sp. All specimens from the St. Louis outlier. *a, b, c,* The holotype. (Yale Univ., Peabody Mus., No. 13946.) *a,* A general view (×5). *b,* To show columella and base (×5); the outer lip is broken. *c,* To show color pattern (×4). *d,* A paratype from the base of the Pawnee limestone (×8). Note the course of the growth-lines on the final whorl. (Yale Univ., Peabody Mus., No. 13948.) (p. 446)

2*a, b*—*Orthonema conicum* Meek and Worthen. Both specimens ×4. *a,* The holotype, a specimen with a badly preserved surface. (Univ. of Illinois collections.) *b,* A chorotype showing ornamentation. (Illinois Geol. Survey collections.) (p. 445)

3*a–c*—*Orthonema marvinwelleri* Knight, n. sp. All specimens from the St. Louis outlier. *a,* The holotype, ×8. (Yale Univ., Peabody Mus., No. 13944.) *b,* A paratype, the largest specimen, ×4. *c,* A paratype, ×8. *b* and *c* bear Yale Univ., Peabody Mus., No. 13945. (p. 444)

4—*Orthonema carbonarium* Worthen. Chorotype, ×4. (From the Illinois Geol. Survey collections.) (p. 442)



Knight, Pennsylvanian gastropods

presumably in accord with the requirements of the genus; aperture rhombic; ornamentation four strong revolving carinae, all commonly visible on the whorl-face and arranged in two pairs above and below; the uppermost carina relatively weak, just below the upper suture; the second carina strongly developed and separated from the uppermost by a concave area about one-third as wide as the median band separating it from the equally strong third carina; the fourth carina relatively weak, just above the lower suture, or barely covered by the succeeding whorl, and separated from the third by a concave area comparable to the one between the first and second carinae; color pattern unknown.

O. marvinwelleri is very distinctive in that it generally shows four revolving carinae between sutures, the two inner of which are notably strong, and in its flat base.

The name is in honor of Dr. J. Marvin Weller of the Illinois State Geological Survey.

I have four specimens of the species, none of them consisting of more than five of the latest whorls, all from the base of the Pawnee limestone at Loc. 6 in the St. Louis outlier. The holotype bears Yale Peabody Museum No. 13944 and the paratypes 13945.

ORTHONEMA CONICUM Meek and Worthen

Plate 57, figures 2*a–b*

Orthonema conica MEEK and WORTHEN, *1866*, Acad. Nat. Sci., Philadelphia, Proc., p. 270; *1873*, Illinois Geol. Survey, vol. 5, p. 590, pl. 2*a*, fig. 5. Lower Coal Measures (St. David limestone), Hodges Creek, Macoupin County, Illinois.

Measurements of *Orthonema conicum*

	A	B
Number of whorls	11[a]	11[b]
Height	17.7 mm.	16.5 mm.
Width	7.5 mm.	7.25 mm.
Ratio of height to width	2.35	2.3
Ratio of height of body whorl to total	0.49	0.50
Pleural angle	25°	25°

A. The holotype (Pl. 57, fig. 2*a*).
B. A chorotype (Pl. 57, fig. 2*b*).

[a] Estimated on the assumption that three apical whorls are missing.
[b] Estimated on the assumption that one apical whorl is missing.

Relatively large (for the genus), high-spired, nonturreted gastropods with gently convex sides; whorl profile gently arched, with barely a trace of angulation over the revolving carinae; base flatly rounded; sutures groove-like; columella arcuate; inner lip slightly reflexed; parietal inductura thin, inconspicuous; outer lip with a characteristic, though slight sinuosity, passing obliquely backward from the upper suture, with a slight convexity toward the aperture until it meets the upper of the two revolving carinae, then straightening out and passing nearly, though not quite vertically across the whorl-face and becoming slightly convex toward the aperture on the base; ornamentation, two low obscure revolving carinae, the upper passing around the whorl about one-third the suture-to-suture distance below the upper suture, and the lower about half as far above the lower suture; three or four very low, obscure revolving ridges on the base; growth-lines sharp, but not exaggerated; color pattern unknown.

This, the largest of the known species of *Orthonema*, is clearly distinguished by its size, its robust convexly-sided spire and its two weakly-developed revolving carinae. Moreover, its outer lip is more strongly sinuous than any species except *O. inornatum*.

I have before me Meek and Worthen's holotype and a paratype, both with somewhat corroded surfaces, and a very well-preserved chorotype loaned me by Dr. J. M. Weller. All are from the same horizon, the St. David limestone, the holotype and paratype from Hodges Creek, Macoupin County, Illinois, and Weller's chorotype from N. center, sec. 30, T. 11 N., R. 10 W., Greene County, Illinois.

ORTHONEMA INORNATUM Knight, n. sp.
Plate 57, figures 1*a–d*

Measurements of *Orthonema inornatum*

	A	B
Number of whorls	18	11
Height	19.0 mm.[a]	7.0 mm.
Width	4.8 mm.	2.2 mm.
Ratio of height to width	3.95	3.18
Ratio of height of body whorl to total	0.37	0.32
Pleural angle	12°	17°

A. The holotype, my largest specimen (Pl. 57, figs. 1*a*, *b*, *c*).

B. A paratype, an early ephebic individual (not figured).

[a] Estimated on the assumption that two apical whorls are missing.

Moderately small, very high-spired, slender, nonturreted gastropods with sides straight at ephebic and very slightly convex at neanic stages; whorl profile nearly flat, very gently concave above and convex below, adpressed above, evenly rounded on the base, sutures shallow, almost linear; columella slightly arcuate; inner lip slightly reflexed; parietal inductura thin, inconspicuous; outer lip with a characteristic sinuosity, the lines of growth passing sharply and obliquely backward from the upper suture with a marked convexity toward the aperture until just before crossing the faint revolving thread on the upper whorl-face where they curve rather sharply downward and a very little forward to pass down across the lower whorl-face almost without concavity toward the aperture, on the base slightly convex toward the aperture; ornamentation other than obscure lines of growth almost lacking, but an obscure revolving carina or thread on the upper whorl-face about one quarter of the suture-to-suture distance below the upper suture, and two very much fainter ones just above and below the lower line of suture; color pattern, a dark revolving band between the upper suture and the revolving thread and another dark, revolving band along the lower line of suture.

At first sight, *O. inornatum* appears somewhat out of place among the other more strongly carinate species with less sinuate outer lips. Indeed, before the range of specific variation within the genus and the essential unity of pattern of the ornamentation and the course of the outer lip had been thoroughly studied, the species seemed to represent a different and new generic type. Yet the continuity between the more strongly carinate species with almost straight outer lip and *O. inornatum* with almost obsolete ornamentation and a strongly sinuate outer lip is unbroken, and the characters of the ornamentation coupled with the peculiarities of the sinus, and certain other less conspicuous characters, such as the method of closing off the abandoned earlier whorls, knits all of them into a rather compact taxonemic unit.

O. inornatum is very distinctive in its almost complete lack of ornamentation, and its high, many-whorled, nearly straight-sided spire. It is distinguished from smooth species of *Palaeostylus* by its obsolescent revolving carina, its smooth nucleus and the peculiar form of the sinus; from *Meekospira peracuta* by its higher spire with more numerous whorls, by its sinus, revolving carinae, and by the method of closing off the abandoned whorls.

I have six specimens of the species, all from the St. Louis outlier. Five, including the holotype, are from Zone G at the top of the Labette shale at Loc. 43, and one is from the base of the Pawnee limestone at Loc. 6. The holotype bears Yale Peabody Museum No. 13946, the paratypes from Loc. 43, No. 13947, and those from Loc. 6, 13948.

APPENDIX

Correction to previous paper on the Neritidae.

Prof. Carl C. Branson has called to my attention the fact that the name *Naticopsis wortheni* Knight, 1933 (1*f*, p. 377), is a homonym of *Naticopsis worth-*

eni Weller, 1916. I, therefore, propose the name *Naticopsis wortheniana* Knight, new name, to replace it.

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THE ZOOLOGICAL RELATIONSHIPS OF THE CONODONTS[1]

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ABSTRACT

The ideas of previous workers on the zoological relationships of conodonts are presented. Eighteen "conodont assemblages" from the Quadrant shales of Montana are described and figured. The "assemblages" are compared to the tooth structure of various types of vertebrates but are found to be dissimilar in every respect. They are more like, in fact are almost identical to, the jaw apparatus of annelid worm jaws.

Few subjects in paleontology have lent themselves to more controversy then the zoological affinity of conodonts. Probably no group of fossils has been as much studied and as little understood. Since the time of their discovery by C. H. Pander (1)[2] in 1856, they have formed the basis for many discussions. Paradoxically as it may seem, they have seldom been claimed to be the remains of vertebrate animals by students of the vertebrates, or the remains of invertebrates by invertebrate paleontologists. Instead, there has always been a tendency for each group of workers to study them but force ownership upon the other group.

Conodonts have been considered to be the remains of such diverse groups as Pisces, Annelida, Mollusca, Arachnida and Crustacea. Since the publication of Ulrich and Bassler's (2) classification in 1926, however, they have been generally considered as the remains of fish.

Early in October, 1933, samples of a black fissile shale of the Quadrant formation, commonly considered Pennsylvanian in age, from the Big Snowy Mountains in central Montana, were studied for microfossils. This shale contains many individual conodonts but, what is far more important, it has yielded seventy-five complete or partial conodont jaw assemblages. This last group of specimens forms the basis of this paper.

In addition to the jaw assemblages and individual conodonts found, there are numerous pelecopods and a few linguloid brachiopods.

All but one of the different generic types of conodonts found have been identified. They include *Prioniodus*, *Prioniodella*, *Hindeodella*, and *Polygnathus*. It is not proposed at this time, however, to describe any new species or genera of conodonts. On the other hand, a discussion of the "conodont assemblages" from the Quadrant shales should go a long

[1] This paper was made possible through funds furnished by the Montana Bureau of Mines and Geology.

[2] Numbers in parentheses refer to the Bibliography at the end of the paper.

way in answering the old question, "What are conodonts?"

The writer is pleased to acknowledge his indebtedness to Eugene S. Perry, Chief Geologist of the Montana Bureau of Mines and Geology, through whose kindness the samples of Quadrant shale were obtained for study. He is also indebted to Carey Croneis of the University of Chicago for constructive criticism and for his kindness in reading the preliminary conclusions at the 1933 meeting of the Paleontological Society in Chicago. His best thanks are also due A. S. Romer of Harvard University for making important suggestions. The drawings were outlined by the writer and painted by Mrs. Elizabeth Lochrie of Butte, Montana.

HISTORICAL RESUMÉ

Pander considered conodonts as the remains of fish of the selachian or shark type. He entertained no doubt as to their zoological affinities as indicated by the title of the article, "Monographe der fossilen Fische des silurischen Systems des russischbaltischen Government," under which he named and described them.

J. Harley (3) appears to be one of the first to question Pander's disposal of conodonts. In 1861 he expressed the belief that they were the spines from animals similar to Limulus and Squilla.

In 1875 Pander's disposition of conodonts was questioned by J. S. Newberry (4), of Ohio. After studying many specimens from the Cleveland shales, he suggested that they might be annelids instead of fish (Cyclostomata).

G. J. Hinde (5), in 1879, considered them as teeth of primitive vertebrates and compared them with the teeth of the existing myxinoids. He made extensive researches on the annelid jaws from the Isle of Gotland, England, Canada, and northeastern United States, and found many types of conodonts associated with them. He compared the chemical composition of these two different types of fossil remains and found that they were radically different. Furthermore, he found no gastropods in association with conodonts in the same formation. Nor did he find any Crustacea which might have possessed spines resembling conodonts. For these reasons he concluded that the fossils were not of invertebrate origin but belonged to the vertebrates. Nevertheless, he entertained some doubt as to their origin. This doubt is expressed in the statement, "the facts at hand appear insufficient to decide the question."

In 1884, U. P. James (6) regarded them as "the jaws and lingual teeth of mollusks." Few others have followed that suggestion.

In 1886 Rohon and Zittel (7) concluded that "the conodonts have structurally nothing in common either with the dentine of Selachia and other fishes, the horny teeth of Cyclostomi, the lingual teeth of the Mollusca, the hooklets of the Cephalopoda, or the broken segment spines of the Crustacea; on the other hand, both in form and in structure, they agree remarkably with the masticatory apparatus of the Annelida and Gephyrea."

In 1921 the question of the zoological affinities of conodonts was again seriously questioned. At that time W. L. Bryant (8) remarked: "On the whole, the longer I have studied these organisms, the more have I become convinced that the true conodonts have hardly anything really diagnostic in common with annelid jaws." This conclusion was arrived at by a comparison of the structure of conodonts and annelid jaws (scolecodonts). He considered conodonts to be the remains of "some primitive type of fishes."

As early as 1878, Ulrich (9) said that a "striking resemblance" existed between conodonts and the chitinous jaws of liv-

ing annelids. Though he was dissatisfied with this surficial resemblance, he concluded, at that time, that the "most probable explanation," was that conodonts "are the hooklets of species of annelids." But after many years of study, Ulrich and Bassler (2), in 1926, discussed the biological position of conodonts and published the first complete and satisfactory classification. They made a careful study of the teeth and dermal plates of recent fishes (Myxines) and concluded that conodonts were to be considered as "the teeth of primitive fishes and not necessarily all of the same group."

Many scientific workers have considered the affinity of conodonts as undeterminable and have hesitated to suggest their possible relationships. This is exemplified by the remark of A. S. Woodward (10), who says that "their histological structure is so different from that of any teeth known that their affinities are quite undeterminable." This question of doubt is not entertained by some of the most recent workers. Mr. Bryant (8) has "become convinced that the true conodonts have hardly anthing really diagnostic in common with annelid jaws . . . the conclusion seems almost unavoidable that the conodonts must be considered as the dentition of some primitive type of fish."

In 1923, J. M. MacFarlane (11) classifies them as an order "Conodontes" under the Malacodermata. He accepts them "as the circumoral teeth of primitive members of that more primitive group of fishes, the Cyclostomata."

C. R. Stauffer and Helen Jeanne Plummer (12), in 1932, remark, "It is evident that the solution of the problem lies near the fish."

In 1933, A. S. Romer[3] said, "I cannot accept them as the remains of vertebrates."

It has been stated by many writers that the difference in the chemical composition of scolecodonts and conodonts is sufficient basis to warrant separation of the two groups; consequently, it is said, that they belong to animals of a different phylum. Stauffer and Plummer (12) remark that "one of the strong arguments in favor of including the conodonts with the fish is their chemical composition." This point is considered by the writer as of sufficient significance to aid in placing various forms in different orders or families within a phylum, but would be of no greater value in classification.

The foregoing is a sufficient, though not a complete, historical resumé of the ideas of various workers concerning the zoological affinities of conodonts. It indicates that just about as much doubt exists today over this important subject as has existed throughout the period since their discovery.

DESCRIPTION OF "CONODONT ASSEMBLAGES"

Assemblage One

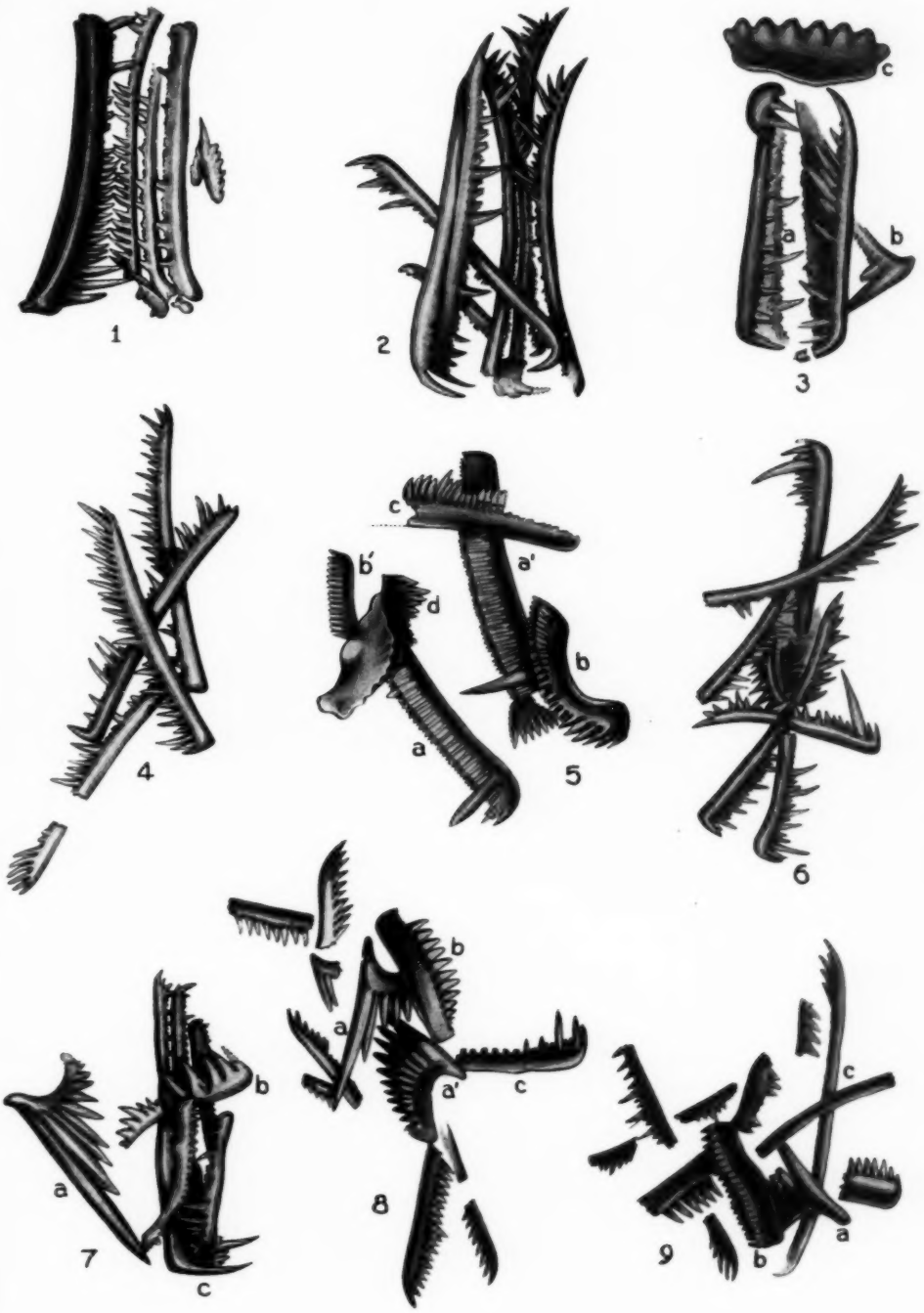
Plate 58, figure 1

In this group there are six conodonts in a fair state of preservation. There is one well-preserved *Hindeodella* and the upper edge of a second can be seen on

[3] Personal communication.

EXPLANATION OF PLATE 58

FIG. 1—Five specimens of *Hindeodella* and a *Prioniodus* (?).
2—Eight Hindeodellas.
3—(a) Four Hindeodellas, (b) *Prioniodus*, (c) *Prioniodella* (?).
4—Four right-hand Hindeodellas. Compare with figure 2.
5—(a, a′) *Hindeodella*, (b, b′) *Prioniodella*, (c) unidentified, (d) undescribed.
6—Six specimens of *Hindeodella*.
7—(a) *Prioniodus*, (b) *Prioniodella*, (c) three complete and two fragments of *Hindeodella*.
8—(a, a′) *Prioniodus*, (b) *Prioniodella*, (c) *Hindeodella*.
9—(a) *Prioniodus*, (b) undescribed, (c) *Hindeodella*.
All figures about ×27.



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the left side of the assemblage. On the right-hand side are three Hindeodellas, the bars of which are successively lower and the teeth of the uppermost specimen overlapping the teeth of the lower one. The main cusp is not distinct in any of the specimens. A fragmentary specimen of what appears to be a species of *Prioniodus* occurs on the outside of the assemblage to the right.

Assemblage Two

Plate 58, figure 2

Assemblage Number Two consists of eight well-preserved specimens of *Hindeodella*. The denticles of four of these specimens point to the left and the denticles of the remaining four point to the right. All of the individuals are well preserved, easily identified and seem to have maintained their natural position. They probably represent the actual position of the teeth in the mouth of the animal. There is a slight tendency for the bars to converge anteriorly. They may have been set in a semicircle as in the mouth of an annelid.

Assemblage Three

Plate 58, figure 3

This unusual group consists of two pairs of *Hindeodella*, a *Prioniodus*, and a *Prioniodella* (?). There are two Hindeodellas on each side of the assemblage. The denticles all point inwardly and are slightly inclined anteriorly. At right angles to the elongation of the assemblage is a specimen of *Prioniodella* (?). The identification of *Prioniodella* is doubtful for due to the fragile character of the entire assemblage it cannot be uncovered more than is shown. To the lower right of the assemblage is the imprint of a *Prioniodus* with its denticles pointing to the left posterior. An unidentified fragment is located in the left anterior of the assemblage.

Assemblage Four

Plate 58, figure 4

In this assemblage are four Hindeodellas with their teeth pointing to the left. This is interpreted as representing half of a group similar to the one picture in Assemblage Number Two.

Assemblage Five

Plate 58, figure 5

Most of the specimens in this assemblage are well preserved. The two Hindeodellas differ from all others described in this paper. The bar is deeply set with numerous small denticles and a large main cusp which is preceded by six sharply pointed denticles. Two Prioniodellas are also present; one each on the right and left side of the assemblage. A specimen of an undescribed conodont (d) covers the anterior end of *Hindeodella* (a). This is a form similar to that mentioned in Assemblage Number Seventeen. An unidentified specimen (c) is anteriorly located.

Assemblage Six

Plate 58, figure 6

There are six specimens of variously oriented Hindeodellas in this group.

Assemblage Seven

Plate 58, figure 7

This assemblage consists of six conodonts. The left specimen is a well-preserved *Prioniodus*. The denticles point to the right posterior and the main cusp is on the outside. On the right-hand side of the assemblage are three more or less complete specimens and two fragments of *Hindeodella*. The teeth point outward and are inclined anteriorly on all but one specimen.

Lying in the center and normal to the elongation of the *Hindeodella* group, with its denticles pointing anteriorly, is a specimen of *Prioniodella* (?).

Assemblage Eight

Plate 58, figure 8

Two specimens of *Prioniodus*, one of *Prioniodella* and parts of at least four specimens of *Hindeodella* are present.

Assemblage Nine

Plate 58, figure 9

One specimen of *Prioniodus*, two of *Prioniodella*, and fragments of at least three Hindeodellas are present in this group.

Assemblage Ten

Plate 59, figure 10

Only three individuals are found in this assemblage, a *Bryantodus*, a *Hindeodella*, and an undescribed form similar to the ones mentioned in Assemblages Number Seventeen and Number Five.

Assemblage Eleven

Plate 59, figure 11

Assemblage Eleven is a fairly complete and well-preserved group. It consists of the following paired forms: *Prioniodus*, *Hindeodella* and *Prioniodella* (?). The left member of *Prioniodus* is on the outside of the assemblage with the denticles pointing posteriorly and the main cusp on the inside. The denticles of the right member of *Prioniodus* (preserved as an imprint and illustrated as seen) point outward with the main cusp toward the anterior end. The specimens of *Hindeodella* lie with their denticles pointing outward and the two converge to a point posteriorly. In the anterior end of the right side of the assemblage are imprints of two broken specimens of what appears to be *Prioniodella*. There is also an imprint of an unidentified specimen in the center of the assemblage with the denticles pointing anteriorly. It is impossible to determine with any degree of accuracy the genus of this latter individual.

Assemblage Twelve

Plate 59, figure 12

A *Prioniodus*, two Hindeodellas and two broken specimens of unidentified conodonts make up this assemblage.

Assemblage Thirteen

Plate 59, figure 13

The same association of genera is found in this group, but the specific characteristics of each member are different than any of the other described groups. The main cusp on *Hindeodella* is preceded by seven small denticles. The specimens of *Bryantodus* and *Prioniodus* also differ from specimens in the other assemblages.

Assemblage Fourteen

Plate 59, figure 14.

Two complete specimens of *Hindeodella* and one of *Prioniodus* compose this group. The relationship of the *Hindeodella* specimens as seen in this assemblage is very common. The teeth of the upper specimen generally rest on the bar of the lower. The main cusps are so closely associated that the lower is commonly completely obscured by the upper.

Assemblage Fifteen

Plate 59, figure 15

This assemblage is composed of two Hindeodellas, a *Bryantodus*, and a *Prioniodella* (?) The *Hindeodella* relationship is similar to that in Assemblage Number Thirteen, but the spacing of the denticles differs. Assemblages Thirteen and Four-

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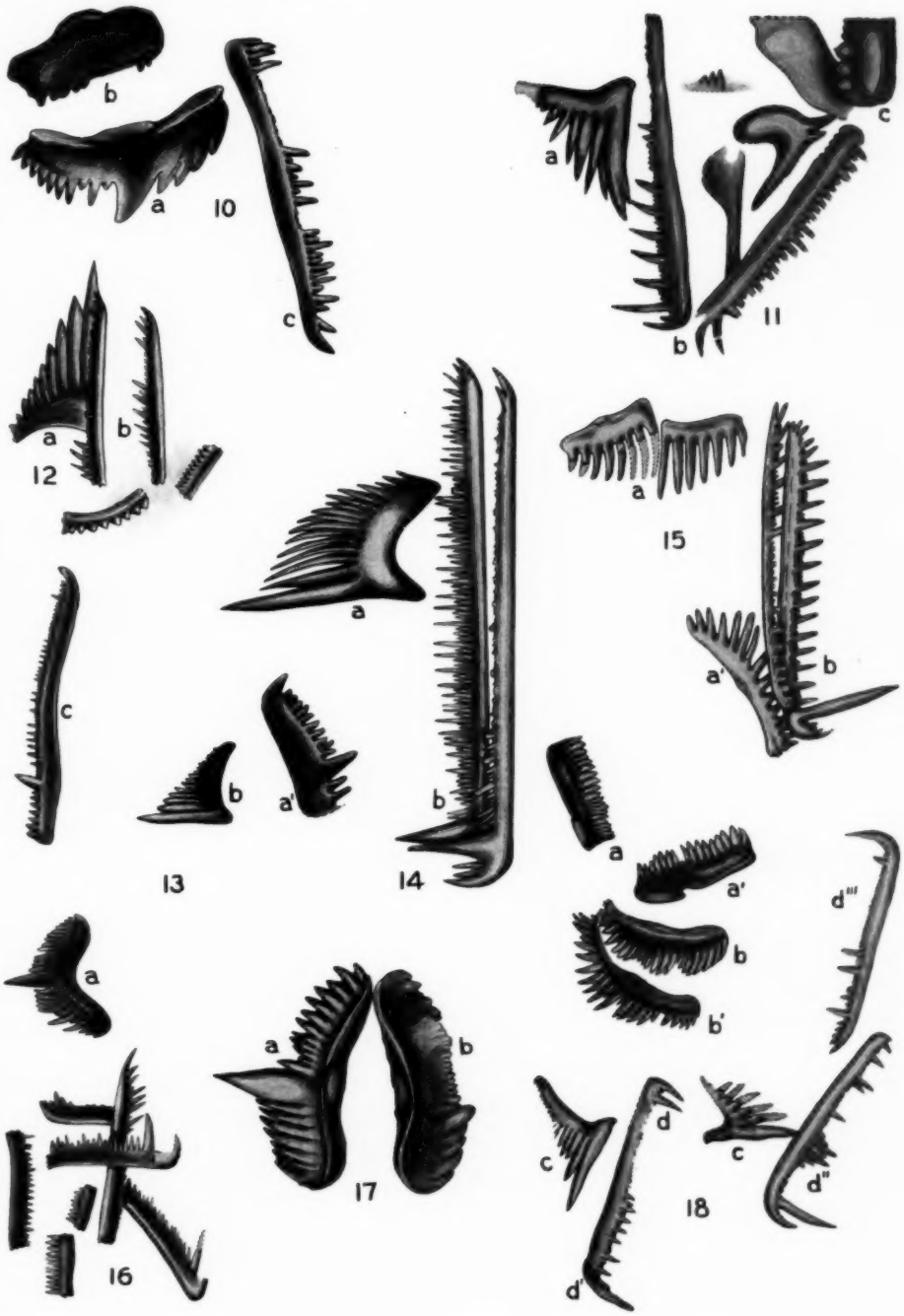
EXPLANATION OF PLATE 59

FIG. 10—(a) *Bryantodus*, (b) undescribed, (c) *Hindeodella*.
11—(a) *Prioniodus*, (b) *Hindeodella*, (c) *Prioniodella* (?).
12—(a) *Prioniodus*, (b) *Hindeodella*.
13—(a, a′) *Bryantodus*, (b) *Prioniodus*, (c) *Hindeodella*.
14—(a) *Prioniodus*, (b) *Hindeodella*.
15—(a, a′) *Bryantodus*, (b) *Hindeodella*.
16—Fragments of three or more Hindeodellas.
17—(a) *Bryantodus*, (b) undescribed.
18—(a, a′) Undescribed, (b, b′) *Bryantodus*, (c, c′) *Prioniodus*, (d, d′, d″, d‴) *Hindeodella*.
All figures about ×27.



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teen probably represent two distinct species of the same genus.

Assemblage Sixteen
Plate 59, figure 16

Fragments of three or more Hindeodellas make up this group. It is similar to Assemblages Four and Six.

Assemblage Seventeen
Plate 59, figure 17

This assemblage consists of only two individuals. The left member is a beautifully preserved specimen of *Bryantodus*. It is of the clear amber type with sharply pointed, cream-colored denticles deeply set into the bar. The right member is a specimen of an undescribed type of conodont, having two parallel rows of laterally fused denticles. Only one row is visible in the picture. The specimen is dark amber in color. This combination is very common and many examples have been found.

Assemblage Eighteen
Plate 59, figure 18

An excellently preserved group of individuals is represented in this assemblage, but unfortunately, their orientation has not remained undisturbed. They have been twisted out of their original position, and for sake of clarity in description, the posterior end of the assemblage has been assumed to be occupied by the forms of *Hindeodella* and *Prioniodus*.

The most posterior forms are a pair of Hindeodellas. These specimens are unique among all Hindeodellas which have been observed by the writer. The anterior end of the upper individual is anteriorly located in the assemblage as it is now oriented. The lower member is almost entirely covered by the upper member. Its anterior end appears to be diametrically opposed to the corresponding end of the upper member. In fact, the ends of the two members are so closely fitted together that they appear to be fused. However, this may be a matter of chance. To the right of this pair is another excellent specimen of *Hindeodella* with its denticles pointing outward and the main cusp posteriorly located. At the anterior end of this specimen is the imprint of a fourth *Hindeodella*, the denticles of which point inward. In the posterior half of the assemblage occurs a well-preserved pair of *Prioniodus*. The denticles of the left-hand member point posteriorly with the main cusp on the inside. The right-hand member of *Prioniodus* lies with its denticles pointing to the right and the main cusp on the posterior margin. In front of the pair of *Prioniodus* is a pair of *Bryantodus*. The denticles of both of these individuals point posteriorly and the two bars are close together. In the anterior part of the assemblage is a pair of conodonts unknown in our modern scheme of classification.

CONCLUSIONS

A study of the photographs and outline drawings on Plates 58 and 59 brings out a number of interesting relationships.

1. Conodonts are paired.
2. They are made up of right and left groups.
3. The pairs are laterals instead of uppers and lowers. In some cases it appears as though they may have been grouped around the mouth opening as in the mouth of a modern annelid. This is an interesting condition and is not suggestive of fish teeth. This situation would also indicate that there was not an upper and a lower jaw, a condition essential to vertebrate animals.
4. There are only a few pairs in each mouth. This appears to be a very essential and important observation because if they occurred in the mouth of a fish, we would expect to find many pairs, or at least, many teeth. But, in no case have more than ten conodonts been observed in one assemblage.
5. In many assemblages examined there are as many as four pairs of teeth

of different architectural design in one mouth. The various pairs represent as many different genera in our present scheme of classification. If these teeth belonged to such an animal as a Myxonoid we would expect to find numerous forms that were identical or at least similar in their general structure, but never the diversity of form that is found.

After extending their study of conodonts to "such recent fishes as the Myxines and small Selachians," Ulrich and Bassler (2) "feel certain the prevalent opinion that many kinds of these teeth may occur in the same mouth, or plates in the same dermal armor, is not warranted by the facts. Except that there are right and left pairs belonging in the case of teeth, to the right and left sides of the upper and lower jaw, the minute teeth, wherever located in the mouth of the supposed living relatives of the conodonts, are essentially alike and thus each kind is characteristic of some particular genus and species."

The conodont assemblages herein described definitely prove that teeth of various kinds, representing more than one genus in our present scheme of classification, existed in the mouth of one individual. Particular attention is called to Assemblage Number Eighteen where *Hindeodella*, *Prioniodus*, *Bryantodus* and one undescribed genus occur.

6. There is a tendency for the largest pairs to be posterior.

7. Six sets of identical assemblages have been found. This would indicate that the preservation was not accidental but natural. Other assemblages are similar to these six identical sets.

8. All of the isolated conodonts in this shale have been recognized as integral parts of known assemblages. This indicates that all conodonts are parts of some kind of a jaw apparatus.

9. There is a lack of a definite pulp-cavity in the denticles of conodonts. A pulp-cavity is invariably found in the teeth of vertebrate animals.

10. Even though the preservation has been perfect enough to make available for study certain of the conodonts in their original association, no other parts of the animal have been observed. This would lead to the conclusion that the animal had no other hard parts, such as scales or bones, to be preserved, but was composed of soft tissues.

11. Some conodonts are fastened or attached in only the posterior or medial portion, whereas the other end is free. This method of articulation is a condition which seems impossible in fish, but is actually the case in annelid worms.

12. Teeth or tooth-like structures are found in the jaws of some arthrodires and acanthodian sharks. However, the architectural design of individual conodonts, the number and arrangement of parts in the "assemblages" show no resemblance to the jaw parts of these forms.

13. There have always been mechanical difficulties in fitting the varied and complicated parts of conodonts into the mouth of a vertebrate. This is not the case with worms. Similar complicated structures are found in modern annelids and are mechanically operated by muscular attachments.

14. All students of conodonts have necessarily observed the perfect preservation of the minute, delicate and sharply pointed denticles. These denticles could not have been used as masticatory apparatus; they would have been worn and the points broken off. However, they could be used in the mouth of annelids to aid the animal in obtaining food without any, or at the most very little, mechanical wear. This is the main use that modern annelids make of their teeth.

15. The arrangement of the assemblages observed in the Quadrant shale of Montana is similar to that in modern annelids.

16. The component parts may be directly compared to the individual parts of the jaw apparatus of modern annelids.

17. There is a repetition of the same specific type of conodont in various assemblages, but in no case is there a mixture of different specific types of one genus in an assemblage.

18. The associations are not due to coprolites. Coprolites are unknown in this shale. The matrix is never discolored around or within an assemblage. The writer has seen many coprolites that contained a heterogeneous group of conodonts and is well acquainted with their nature.

To summarize these points in the discussion of annelid affinities of conodonts, we find that annelid jaws are paired, various structural forms occur in one mouth, they are commonly rights and lefts, or laterals; fewer pairs of teeth are contained in the mouth of an annelid than in the mouth of a fish; individual parts seldom show any essential wear; a muscular attachment is present, and there are no other hard parts present to be preserved.

To the writer it now seems impossible for conodonts to belong to any group of animals other than Vermes. All of my observations indicate such a zoological affinity. Furthermore, there is nothing in the assemblages studied, and herein described, that is opposed to such a conclusion. The many points which have been enumerated make it practically impossible for them to be considered as fish. In spite of these seemingly dogmatic statements, it is realized that the animal which bore conodonts has not been seen; nevertheless, all observations and all evidence available to the writer, point to annelids as the natural possessors of conodonts.

It is probable that one family of Paleozoic annelids possessed a jaw apparatus composed of teeth which we call conodonts; whereas, a second family possessed teeth known as scolecodonts. Those possessing conodonts died out at the close of the Paleozoic; whereas, that family having the scolecodont type of teeth lived on to the present, giving rise to such forms as the modern Nereis and relatives.

CLASSIFICATION OF CONODONTS

Conodont assemblages are not well enough known at this writing to warrant a combination of genera. Furthermore, the writer realizes the impossibility of differentiating the species of an isolated conodont if genera were combined. Therefore, to facilitate the practical use of conodonts, no changes in classification are suggested or deemed advisable at the present.

The writer will make extensive searches for additional assemblages during the summer of 1935.

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SEDIMENTATION AND STRATIGRAPHY FROM MODERN POINTS OF VIEW[1]

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Geology had its beginnings with men who had little training relating to things of the earth and most of them approached the subject with preconceived ideas respecting the earth's origin and subsequent history. They were priests and preachers as Steno and Whiston; physicians as Hutton; botanists as Lamarck and Lister; anatomists as Cuvier; mathematicians as Hooke and Playfair; engineers as Brongniart, and artists as Leonardo de Vinci. It was not until about one hundred and fifty years ago that the first man may be said to have been trained to become a geologist. This was Werner. He was a stratigrapher in that he arranged the rocks of the earth's crust in a definite sequence; all rocks, the result of aqueous deposition from a once universal, but subsequently receding ocean. Werner's scheme was simple in that he postulated each bed of the earth's crust originally to have had distribution over the earth to the extent that the earth was submerged at the time of its formation, each kind of rock being formed at a very definite time in earth history. As time went on it was discovered that the Wernerian scheme failed and through the observations of Hutton and his interpreter Playfair, Von Buch, Desmarest, and others the impracticability of the Wernerian scheme was demonstrated.

The work of Murchison and Sedgwick in England; Logan and his associates in Canada; Hall, the Rogers Brothers and others in the United States; and particularly the Englishman Lyell, relegated the Wernerian hypothesis to the discard, and new ideas took its place in the minds of these and later geologists. However, like the proverbial cat with its nine lives, this hypothesis appears again and again and unconsciously pervades the writings of many of the older geologists and the little thinking students of some of them. There are always many who lag behind the chariot of progress and cherish the old because it is old and reject the new because it is different.

New views, founded upon a large body of facts and subjected to more rigid analysis than those which they replaced, have put the formation of earth materials in a perspective that explains their origin as consequences of environmental conditions operating upon materials of certain compositions. Thus a body of rock in liquid form, popularly known as magma, on cooling assumes a texture and mineral composition consonant upon the rate and place of cooling and the quantity in the liquid of such vaporous materials as H_2O, CO_2, CO, N., etc. A given body of such liquid rock will form a solid of which the texture may range from extremely coarse to extremely fine. It may be glassy or granitoid, a pumice or a scoria; all consequences of the original composition and the environmental conditions.

After the decline of the Wernerian doctrine, sediments at first were relegated to the realm of simplicity. Geologists observed the sands and gravels accumulating on beaches and elsewhere and it was obvious that their cementation would result in sandstones and conglom-

[1] Paper read at annual dinner, Society of Economic Paleontologists and Mineralogists, Dallas, Texas, March, 1934.

erates; muds were seen to be accumulating in various places and it was but a step to their consolidation into shales; animals were growing shells on the sea bottom and these made limestones. A part of this simplicity probably was an outgrowth of the Wernerian hypothesis, but it was largely due to the assumed comparative difficulty of formation of the materials of igneous and metamorphic rocks. Everywhere the sedimentary materials are stratified and this structure was assumed to be inherent, and resort was had to the explanation that the waters carried different materials at different times and thus came the stratification.

Prominent works on petrology in the English, French and German languages ordinarily devoted only a few pages to sedimentary rocks and merely stated that sedimentary rocks are stratified without explaining stratification. Petrology has been largely a study of igneous rocks and sedimentary rocks have received scant consideration. Here and there a geologist undertook a casual study of sediments, but there was little attempt at organization of the data. Such was the situation in the early part of this century.

Very early students and others observed the fossils in the sedimentary rocks and the earliest recorded students, the Greeks, correctly interpreted them as remains or organisms. In the Middle Ages and up to a couple of hundred years ago they were described as *Lusus Naturae*, figured stones, and referred to an inorganic origin. To some they were the remains of organisms that perished in the flood. Many placed them in the same category as concretions. Their origin was ascribed to the stars, the devil, and other impossible and fantastic causes. Beginning with Hooke and finally with the Frenchmen Lamarck, Cuvier, Brongniart, the German von Buch and finally with the civil engineer, William Smith of England, fossils attained a correct explanation and gained significance as indicators of geologic time. As organisms, fossils must have been controlled by environmental factors, but this fact was forgotten, or received little attention, and rock formations were correlated, or not, on the basis of whether certain fossils were or were not present. The European geologists early awoke to the significance of environment in the distribution of organisms, but we in America have lagged far behind.

It was early noticed that there are breaks in the succession of fossils. This seems to have been first emphasized by Cuvier and Brongniart from occurrences in the Mesozoic and Cenozoic of the Paris Basin. The breaks were ascribed to floods or catastrophes like that in which Noah is reported to have floated around for forty days and forty nights before he landed upon the summit of Mount Ararat. When the universal floods had been relegated to the limbo of things that had never occurred, resort was had to land intervals and wherever a biologic break was encountered, an unconformity and a land interval were postulated. This was the universal condition up to about twenty-five years ago. Little consideration was given to the possibility that the sites of deposition might have reached positions where deposition was not possible or that the bottom might have become inhospitable for organisms.

The Wernerian hypothesis postulated gradual emergence of the land areas from beneath a universal ocean. This was supplanted by the Cuvierian hypothesis of several floods and emergences. Others supplanted this view with that of some areas having always been land and later came ideas of universal and world-wide uplift, these times of universal uplift being made the boundaries between the eras of earth history. They are the critical periods of some stratigraphers. Thus we are told of the universal break between the Cambrian and the pre-Cambrian, the Permian catastrophe with its assumed total elimination of Paleozoic organisms, the great break between the Cretaceous and the Tertiary, the two last particularly interesting because for

many years geologists have disagreed as to what strata should be included in the top of the Cretaceous and what begin the Tertiary and the exact position of the boundaries of the Permian. Suess explained the assumed world-wide character of certain of the breaks as due to sinking of the ocean basins whereby waters were generally drawn from the lands, and Chamberlin and Salisbury adopted this idea to the same end. All the time these hypotheses were considered it was fully understood that only a small part of the earth had been geologically explored,—the situation at present —and that the assumed universal breaks rested upon data commensurate with the extent of exploration. It is by no means certain that any of the eras are separated by stratigraphic breaks coextensive with the land areas and it may be considered certain that beneath the sea there are sections bridging every break. The critical periods are probably critical only locally and figments of the imagination born in ignorance for the world as a whole.

Thus we arrive at the position that old views have been and are being challenged, that traditions—and many of them can hardly receive a more respectful designation—have been and are being analyzed and the bases for the statements in many text books have been and are being sought. It has been learned that some statements supposed to be factual rest on no data at all and must have been created almost entirely from the imagination. This, of course, arose from lack of knowledge and explanations were devised which explained, even if they were not correct. This is emphasized by such things as mud cracks, described in textbooks up to less than twenty years ago as usually being six-sided and having developed from cracks originating and extending from a point. These cracks were stated to make angles of 120° with each other and through intersection with other sets of cracks originating at other points gave rise to the supposed six-sided polygons. As a matter of fact, experimental data with many kinds of conditions show that the cracks rarely, if ever, develop in this way, that the angles where the cracks meet bear little or no relation to 120°, and that the polygons are rarely six-sided. One well known textbook states that mud cracks are characteristic of the tidal zone of the sea and refers in illustration to mud cracks on the Missouri flood plain near Kansas City, Missouri.

In this reexamination of old geology, sediments and fossils quite naturally come in for their innings and a new world has been discovered, or, paraphrasing the Scripture, the sedimentationist, like Saul going forth to find his father's asses, has found a kingdom. Far from finding sediments a matter of simplicity, it has been discovered that they are complex and their origins are complex, that the origins of many kinds of sediments are unknown, that the origins of many of the structures are unknown, that each environmental condition produces some characteristics in the sediments deposited, and that for many types of sediments which are deposited there are corresponding faunas and floras. These discoveries were not made by the petrographers—they drifted along as if the only rocks worthy of consideration are those of igneous and metamorphic origin. The discoveries were made by paleontologists and stratigraphers as exemplified by Vaughan, by structural geologists as exemplified by Barrell, by physiographers as Blackwelder and Trowbridge, and by economic geologists as Milner and Boswell.

I propose to discuss some of the advances made and possibilities to be made in the fields of sedimentation and the coordinate and handmaiden fields of stratigraphy and paleontology although it should be stated that each of these divisions of geology is handmaiden to the others.

ADAPTATION OF SEDIMENTS AND ORGANISMS TO ENVIRONMENTS

Organisms are adaptations to environment; they are the resultants of the long

sequence of environmental factors to which they and their ancestors have been exposed. This fact is, and has long been well known. It is old biology. That it has received little attention from stratigraphers is patent from the reading of most works on stratigraphy published prior to about 1910 and many papers of later date tell the same story, and, as stated by Milner, "stratigraphers are apt to neglect the significance of the environment for the cult of the organism and the intimate detail of succession."

Sediments are produced, transported, and deposited as consequences of the environmental factors prevailing at the places of deposition, and after deposition they become factors of major importance in controlling the distribution of the organisms of the bottom, which organisms on death become sedimentary materials.

Animals have different degrees of sensitivity to environmental factors. Some are little sensitive and may be found in varying degrees of abundance over extremely wide areas with considerable range of environmental conditions. On the other hand, most plants are extremely sensitive as exemplified by some rhododendrons which endure cold with difficulty and will not thrive on soil in which much lime is present. Some plants are adapted to sand barrens, others thrive on such organic regolith as the peats, and still others are so strongly calciphyllic that they die if the soil does not contain lime. The plants living in the various environments in their turn become environmental factors and furnish homes, food and protection for other plants and animals and these latter in their turn become environmental factors for still other animals and plants, the entire sequence not being present if the first factor is wanting.

The problems are extremely complex and it is doubtful if any large part of them is understood for any environment. The results are extremely important for stratigraphy, as organisms appear and disappear in the rocks of the geologic column without, as yet, adequate explanation as to what were the causative factors for such appearance and disappearance. Reference to movements of sea level whereby depths of water and positions of the strand line were changed are the ordinary explanations.

Sediments and organisms are more or less interwoven in their relations to each other, and sediments, like organisms, show different degrees of sensitivity to environments with probably the higher degree residing in the sediments, as all sediments seem to be closely related to environmental conditions and there are none which are so independent of the environments as the common dandelion. Some sediments, as the sands, may have the appearance of being only slightly sensitive but when these are critically studied it is readily seen that the sands are by no means alike and have their detailed characteristics determined by rather narrow ranges in the environmental factors. So far as I am aware, there are no sediments which possess such cosmopolitanism as some animals and plants.

It would seem unnecessary to state that the environmental conditions in any large body of water would be of wide range with corresponding ranges in the variety of sediments deposited and organisms dwelling on the bottom. This is the case now and it is most reasonable to assume that every large body of water of past geologic periods possessed a wide range of environmental conditions and deposited sediments and supported a flora and fauna commensurate with the environmental range.

ENVIRONMENTAL FORMS AND DISTRIBUTION OF MARINE ORGANISMS

The organisms of the water are in the three forms of plankton, nekton, and benthos. The first is more or less independent of the environment of the bottom—currents controlling the travels; and temperature, chemical and physical characters of the water, food supply, etc., determining persistence of the organisms

in the range of waters of the transporting currents. Nekton, likewise, are more or less independent of bottom conditions, various forms thriving equally over mud, sand, and rocky bottoms so long as other controlling factors are not prohibitive. Many, and perhaps most nekton, however, have some relations to the bottom environment in that the organisms of the bottom furnish in part the direct and indirect food supply and thus the numbers tend to be greatest over those bottoms which produce food in greatest abundance.

Most nekton and plankton if introduced into fresh waters would be troubled and probably die. This might occur in delta bays and lakes, in the lagoons behind some barrier islands, in estuaries, and about the mouths of rivers following heavy rains. Destruction due to heavy rains have been described off the coast of India, on the Great Barrier Reef of Australia, and elsewhere. Fresh-water forms experience similar difficulty if introduced into salt water. Muddy waters taking the place of clear usually make it difficult for both nekton and plankton.

The benthos are narrowly limited by the nature of the bottom materials. Certain forms thrive best on mud bottoms, others upon sand bottoms, and others must have rock or shell bottoms. Some dwell in greatest abundance where marine plant life thrives, others where such is rare. Additional factors are depth of water, agitation, turbidity, temperature, and the presence of other organisms to furnish food and protection. In turn, each form of benthos may, and most probably does, have influence in determining the presence of other benthos and also the presence of certain nekton and plankton. The most important and profound factor of the environment in determining the character of the benthos seems to be the nature and physical properties of the bottom materials, but it must be fully understood that these in turn are due to such environmental factors as depth, temperature, agitation, supply, etc. Kindle's[2] work on the organisms of the Bay of Fundy is illustrative in this respect and he concludes that to the extent the physical and chemical characteristics of the bottom materials are similar, so the faunas living upon them approach similarity, and the greater the differences in the physical and chemical composition of the bottom materials the greater the differences in the faunas living upon them. Kindle's studies further indicate the fallacy of the contention of some paleontologists that current action integrates the bottom differences of the preservable organic remains and the fallaceous conclusion that the fossil faunas of all environments become uniform from this cause.

The work of Walther[3] on the faunas of the Bay of Naples has shown a striking occurrence of the control exercised on the character of the benthos by the nature of the bottom. Tauben Bank rises from a muddy bottom ranging from 200 to 500 meters below sea level to the top of the Bank extending from 45 to 50 meters below sea level. In 1885 the Bank had a luxurious development of plant and animal life and this existed in the midst of, but above, the relatively poor flora and fauna living upon the muddy bottom. Upon the top of the Bank there lived in 1885, 360 species of animals, upon the mud bottom 142 species. Seventy species were common to the two environments. The number of species living on the top of the Bank which might become fossilized was 310 and on the mud bottom 45. The number of common species was 14. The two environments do not differ so greatly in their physical characteristics as they do in their faunas. Similar control over the benthonic faunas by the bottom material is known in the geologic column. The author has described several instances in the Anticosti Island succession and has cited various observations made by

[2] Kindle, E. M., *Am. Jour. Sci.*, (4) vol. 41, pp. 449–461, 1916.

[3] Walther, J., *Abhandl. d. k. Preus. Akad., Wiss. verlag. Phys.-Math. Cl.*, pp. 1–49, 1910.

others,[4] and it is likely that examples will become numerous as soon as stratigraphers apply the principle that environment was an important factor in organic control in the past and discard the theory that wave action distributes organic matter so as to make the shells on a sea bottom everywhere similar.

It should always be remembered that each change in sediment, either laterally or vertically, creates a new environment —was caused by a change in environment—and if modern marine biologists are correct, these changes should be accompanied by concomitant changes in fauna and flora. A change in flora in turn has repercussions on the fauna. Changes in sediments are more likely and more common in shallow than in deep seas and thus should have been extremely common in the shallow epicontinental seas of the Paleozoic and other eras. This is what is found to be the case in the vertical, and in harmony with the principle of Walther such denotes similar variations in the lateral sense.

Up to very recent time, geologic philosophy has been so permeated with the theory that changes and differences of faunas are fundamentally due to advances and retreats of the sea, or to separating land barriers, that little or no attention has been given to the possibility that these faunal differences and changes might be due to differences or changes in the faunal environment. I am of the opinion that the many movements of the land and sea and many of the land barriers which have been postulated to explain the differences in faunal content of the rocks of such shallow water areas as must have existed in the Appalachian Geosyncline, about and over the Cincinnati Anticline, and similar ancient land bodies, will ultimately in considerable degree yield to explanations referring the faunal differences to variations in environmental factors, particularly variations in the character of bottom materials which, as already pointed out, are the resultants of a large number of environmental factors. I am also of the opinion that many of the postulated land barriers will ultimately be relegated to the limbo of things forgotten. These traditional theories, like many of their predecessors, will have served their purposes.

[4] Twenhofel, W. H., Environment in sedimentation and stratigraphy: *Geol. Soc. America, Bull.*, vol. 42, p. 413, 1931.

CHANGES IN THE BENTHOS AND CHANGES IN THE ENVIRONMENT

In the Anticosti Ordovician the genus *Beatricia* is characteristic of a zone in the Vauréal formation. It then disappears and reappears several hundred feet higher in the section. Why did it disappear? Evidently some environmental factor entered, or departed, and drove it from the bottoms of its previous occupancy. What the present or missing factors were has not been determined and it is possible that they can not be determined. Where did the organism live in the meantime, as live it must have? The place or places have not been found. Some day they may be, and it is possible that the strata representing the bottom or bottoms of survival may be correlated with one of the zones of the Anticosti succession in which its remains occur; which, probably will be decided on the basis of the associated species. Recurrence of faunas, which also means recurrence of environment, was a favorite idea with the late Henry Shaler Williams, but not a great deal has been done with it since this time. However, there are no reasons for not believing that it may have occurred many times.

CONTROL OF DISTRIBUTION OF NEKTON AND PLANKTON

The distribution of the nekton and the plankton is independent to a considerable degree of the character of the bottom materials, and hence their occurrences in bottom sediments does not state a great deal with respect to the environment in which the containing

sediments were deposited, and the latter in their turn tell little of the environment in which the contained plankton and nekton lived. The planktonic graptolites in life probably lived in all waters not too cold, too salty, or too fresh, so far as it was possible for currents to carry them into such waters, but their remains would have settled to all bottoms beneath waters into which their living or dead bodies were carried, even to those bottoms over which the overlying waters were too cold, too salty, or too fresh for the organisms to dwell therein. They could have drifted into fresh-water lagoons behind barrier islands, into the lakes upon delta plains, into fresh-water estuaries, and anywhere else to which the tides, oceanic currents and wind currents might have carried them. Thus, it is idle to speak of "graptolite seas" until it has been definitely shown that the sediments which contain the graptolites in large numbers actually were deposited in seas wherein the graptolites lived, instead of being the sediments of waters into which the graptolites drifted after death, or into which they drifted alive and were killed because of the environment being unfit for their occupancy. It may have been the case that the graptolites did not live at all in the waters on the bottoms of which they entered the sediments in greatest numbers, these sediments merely holding them because of being deposited under conditions favorable for preservation. The general occurrence in occasional layers harmonizes with this suggestion. Similarly, such things as skeletons of fi h and sharks' teeth may indicate little or nothing with respect to the environment of deposition of the sediments in which they are entombed. Living shelled protozoans of planktonic habit are distributed in all waters suitable for their dwelling, but their occurrence in sediments has little value for determination of the environments in which the containing sediments were deposited, as the dead shells may drift anywhere.

ENVIRONMENTS OF LIFE, DEATH, AFTER DEATH AND BURIAL

In any consideration of the environments of organisms, four phases of the individual organic history must be considered. These are the environments in which the organisms live, the environments in which they die, the environments in which the dead bodies and the appendages endure after death, and the environments in which the preservable remains are entombed. These four environments of an individual's body and its parts may be the same, as for instance, the skeleton of a coral attached to the place whereon it grew; but, on the other hand, the environment of entombment may be neither that of life, that of death, nor that of existence after death. In life an organism is held to rather narrow environmental conditions by those factors which have organic control; after death it behaves as an inorganic sediment and is controlled by altogether different environmental factors, and the entombment of its preservable parts may bear no relation to the life determining factors. In life the common sea urchin of the Gulf of the St. Lawrence, *Strongylocentrotus dröbachinesis*, requires certain marine associations. After death its shells are found in shallow and deep waters on bottoms where it never dwelt; on the marine marshes where it was carried by waves, tides, and animals, again where it did not and could not dwell; and as food for crows, gulls, and probably other birds, it is carried inland miles from the sea for possible entombment in peat beds and in the deposits of streams and lakes. Fish float for a long time after death and thus they may enter waters in which they did not and could not live. The environment of entombment of the planktonic graptolites and trilobites in many instances was probably not that of life and it may not have been that of death. Trilobite and graptolite remains and much other organic matter have low density and much surface for volume and hence could be carried by waters of

low competency to environments quite different from those in which the organisms lived or died. In the Upper Mississippi Valley essentially all Cambrian strata carrying organic remains have them in the form of trilobite fragments and delicate brachiopods, and at the same time most of these strata possess depositional features showing vigorous wave and current action and it seems probable that the environment of deposition, or entombment, in many instances was entirely different from that of life, and thus the former may not give a true picture of the life of that time in these seas. The Gulf of Kara Bogaz has a current flowing into it from the Caspian Sea, the current being of such competency as to build a delta. The waters of the Gulf are too salty to support much life, but organisms float into it from the Caspian to die shortly after arrival, the numbers at times being said to be enormous. The remains are probably being entombed in the deposits of the Gulf where they may be found by some geologist of the future, who, if he assumed that the plankton and nekton indicated by these remains illustrate the life of the Gulf of Kara Bogaz, would most certainly reach erroneous conclusions both as to life of these waters and the salinity of the waters that this life could endure. These organisms are being entombed not where they lived, but where they died. Shells of organisms living in polar waters are carried to warmer latitudes by the icebergs originating where the animals lived and died, but the organisms are being entombed in environments which are different from either. In May, 1928, the strand line near Wilhelmshaven, Germany, was covered with thousands of bettles, bugs, moths, etc. These lay on the beach in a band 20 to 50 cm. wide near the line of the swash (spulsam). They seemed to have been drowned in the sea following an east wind and were washed from the sea to the beach. On the beach they were mingled with marine shells with the result that the entombment of marine shells and land insects became possible, the place of burial being neither the place of death nor that of life for either the shells or the insects.

Entombment of marine organisms in terrestrial environment may be brought about by washing to the beach of shells of protozoans and immature shells of larger animals whence they may be carried inland by winds and buried in environments which represent neither those of life, nor those of death. The celebrated protozoan sands of Dog Bay on the Galway coast of Ireland and the shells in the Bermuda dune limestones are cases which are well known. It has lately been shown that the sea coast dunes of some parts of Hawaii contain twenty-nine species of marine invertebrates and the shells of four land-snails, of which none is in the environment of either life or death.[5]

ENVIRONMENT IN PRESERVING ORGANIC MATTER UNTIL ENTOMBMENT

Whether organic matter remains preserved until entombed depends upon environmental conditions. There are many environments teeming with life, yet the conditions are such that little or nothing is buried, and hence this life leaves no record of its presence. This fact has long been recognized by the vertebrate paleontologists, but does not seem to have received much consideration from those who worship at the shrine of the invertebrates.

Land organisms do not have much chance to become buried in materials favoring preservation, and thus remains ordinarily are not common. Thus the organisms of uplands, dry prairies, and deserts of past geologic periods are not well known, but every one appreciates that these environments were probably populated in numbers commensurate with the food supply at all times when the lowlands were populated. Conditions are vastly better in swamps and lakes, but generally poor in rivers, although

[5] Hinds, N. E. A., *Bishop Museum, Bull.* 71, p. 72, 1930.

there are several cases of remarkable preservation in river deposits.

As noted above, many black shales are characterized by the abundant horizonal occurrence of planktonic graptolites, but this abundance is probably not a consequence of their having been more numerous in these waters than elsewhere, but rather because the bottom conditions which gave rise to the black shales also developed an abundance of hydrogen sulphide and this, with the physical character of the bottom, eliminated the scavenger organisms thus permitting the graptolite and other delicate organic remains to escape destruction until buried beyond possibility of molestation. Graptolites probably lived and died in waters over other marine bottoms in as equal abundance as over the black mud bottoms, but on settling to the bottoms from these other waters they descended into the capacious maws of the numerous organisms which feed on organic matter. The results are as we find them: remains of delicate organisms are not found in as excellent preservation in deposits made on bottoms which were favorable to scavengers as they are on those bottoms of which the sediments indicate conditions unfavorable to the latter. Bottoms having conditions favorable to a large population of those organisms which feed on organic matter would not be likely to have delicate organic remains persisting for a long time.

Some mollusks, holothurians, and annelids eat the bottom materials for the contained organic matter and Buchanan[6] has stated that "the matter forming the bottom of the sea is continually passed and repassed through the bodies of the numerous tribes of animals which demonstrably live on the mud and its contents." Cambrian sandstones of the Upper Mississippi Valley are literally crowded with burrows; similar abundance is shown in some Ordovician limestones of the same region; and it is obvious that the materials of these strata made repeated passages through intestinal tracts of organisms and thus lost the organic matter which probably once was present. In addition to the macroscopic scavenger and burrowing organisms, sediments usually seem to be filled with microscopic forms and these continue the work of destruction after the macroscopic forms have ceased.

It seems probable that in environments with slow accumulation of sediments little is left to record the presence of the numerous organisms which dwelt on the bottom and in the waters above. The only evidence of the one time presence would consist of comminuted shells, which would not be likely to persist in all cases because of easy recrystallization due to fine condition. There are many marine limestones which to the eye carry little or no organic matter, but thin sections show many of these to be filled with such in various degrees of minute fragmentation with the containing rocks showing nothing to suggest wave action to a degree commensurate with the results observed. The fragmentation, which obviously is physical, must be referred to the work of scavenger organisms. Evidently these rocks accumulated in an environment favorable for the life activities of the organisms, but at the same time one inimical to preservation until entombment.

Entombment is determined by the rate of accumulation of the entombing sediments, and if these are being slowly deposited there is little chance for organic materials to be preserved unless the conditions are like those of the waters in which the black shales were deposited, thus preventing bottom-eating organisms from entering. It was the conclusion of Wepfer[7] that absence of fossils in many sediments is a consequence of too slow, or cessation of, deposition of inorganic sediments, and abundance the converse that deposition was sufficiently rapid to bury organisms as rapidly as they died,

[6] Buchanan, J. Y., *Royal Soc. Edinburg, Proc.*, vol. 18, p. 20, 1890–91.

[7] Wepfer, E., *Zeitschr. d. deutschen geologischen Gesell., Monatsberichte*, Bd. 74, no. 1, pp. 89–147, 1922.

but not so fast as to make the conditions unfavorable for existence. The writer fully accepts this conclusion as of general application. Many marine limestones overlain by shales contain excellently preserved shells on the upper surfaces, a preservation readily explained on the basis that the overlying shales were deposited sufficiently rapidly to bring about entombment before the shells had been seriously injured by scavenger organisms.

Only under conditions of rapid burial is there a certainty of preservation. With too slow deposition, on the one hand, leading to the disappearance of organic matter, while at the same time giving under ordinary conditions a most favorable environment for organisms, and on the other hand, too rapid deposition making the conditions too inhospitable for those organisms, but the most favorable for entombment, it seems a logical deduction that an abundance of fossil organic material in excellent preservation implies a nicely balanced situation which did not often occur.

INDIRECT CONTRIBUTIONS OF ORGANISMS TO SEDIMENTS

Another important field in which much is being done is that relating to the indirect contributions of organisms to sediments. About 50 years ago Buchanan made the statement given earlier that the bottom materials of the ocean almost as a whole pass through the intestinal tracts of organisms. The materials are ejected as excrements in the form of small pellets, better known to geologists as coprolites. Buchanan made the further important observation that many pellets are glauconitized to various degrees, some completely so, others showing only a beginning. This statement seems to have been largely forgotten and glauconite passed into a stage wherein it was explained in other ways. However, it is certain that all the materials ejected as excrements have not been changed to glauconite and that many rocks should contain evidence of the excremental particles, but few have studied rocks from the point of view that they may have been made or modified by passing through the intestinal tracts of organisms. It has already been noted that the finely fragmental state of the organic matter in many limestones owes this condition to being ground up in intestinal tracts. It has been suggested that the spherulites in the Rocky Mountain phosphates may be of coprolitic origin but proof seems wanting. Some Mississippian limestones of Kentucky contain rounded bodies of ground-up materials which seem best interpreted as coprolitic. Lately, two Japanese geologists have rediscovered the discovery of Buchanan and have found that parts of the shallow sea bottom around the Japanese coast are covered with pellets best interpreted as the excrements of marine organisms, and with Buchanan they observed that these show various stages of glauconitization.

Organisms indirectly contribute to many forms of sediments. They have both constructive and destructive influence in the formation of limestones. They participate in the formation of sulphates, sulphides, some iron deposits, the phosphates, perhaps the sedimentary feldspars, and several other substances.

CHANGES IN SEDIMENTS ANTECEDENT TO LITHIFICATION

Sediments when first deposited may be designated as *raw* and these sediments may bear little resemblance to the form they may attain just prior to lithification. Quartz sands obviously can undergo little change, but muds, marls, and organic sediments may undergo profound changes. Bacteria, annelids, and other micro-organisms live in great numbers in the sediments on and immediately below the surface of a deposit in numbers commensurate with the conditions; bacteria, in particular, being present in numbers ranging to many thousands, and even millions per cubic centimeter. Sediments on the bottom of lakes about Madison, Wisconsin, when first deposited are black and rich in organic matter, but descendants of similar sediments

now buried to a depth of about 6 feet are gray to white in color and contain only a small quantity of organic matter. The change in color and the elimination of organic matter are due to the work of micro-organisms. The freshly deposited, or *raw sediments* of these lakes would seem excellent as source materials for petroleum, but at a depth of several feet descendants of similar *raw sediments* contain little that is possible of producing petroleum. Conclusions respecting source materials based on analyses of *raw sediments* are considered of little value in postulating the environments in which petroliferous substances accumulate, as these *raw sediments* at a depth of several feet may be altogether unlike the appearance at the surface and may have entirely lost their entire content of organic matter. The problem of source materials and environment of origin of source materials can only be solved by studies of sediments collected beneath the surface at depths and under conditions precluding further work of destructive micro-organisms. The many sediments analyzed by Trask[8] seem to have been largely in the *raw state* and as such do not afford warrant for reaching general conclusions.

Any form of organic activity in sediments usually initiates a chain of activities of other organisms of which some are destructive of the products formed by previous organisms. Organisms producing carbon dioxide lead to the solution of carbonates; organisms producing hydrogen sulphide lead ultimately to the precipitation of calcium sulphate.

PETROLOGY OF SEDIMENTS

As previously stated, until very recent date petrology as a branch of geology was almost entirely limited to the study of igneous and metamorphic rocks and no or very little attention was given to those of sedimentary origin. We in America have advanced somewhat from that position today, but our British and French colleagues have been giving attention to the petrology of sediments for the past several decades and the names of Cayeux in France and Mackie, Milner, and Boswell in the British Isles are well known and they and their colleagues have built up an important literature in this field. M. I. Goldman, Ralph Reed and Fannie Carter Edson have been the pioneers among American students. The field of sedimentary petrology is almost a virgin one in America and, for that matter, in most parts of the world. It is a field of great importance to economic geology in determining the distribution of economic minerals of sediments and thence tracing them to the source rocks; and to stratigraphy as an aid in correlation. A most interesting application is that relating to historical geology and paleogeography in that the allothogenic minerals of a sedimentary rock may indicate whether the immediate source rocks were igneous or sedimentary, and thus the paleogeography and historical geology of the region may be defined in a manner hardly possible in any other way. Thus, in the Upper Mississippi Valley it has been determined that the source rocks of two of the Upper Cambrian sandstones were sedimentary and not igneous and this establishes the occurrences of extensive sedimentary terranes of sandstones before Upper Cambrian time. Petrographic studies of the Huronian Baraboo quartzite indicate that it probably was not an important contributor to the Cambrian sandstones and also indicates that it, too, acquired its sedimentary materials from sedimentary and not igneous terranes. This postulates large sedimentary formations of pre-Baraboo quartzite age from which the Baraboo quartzite sands were derived. The Coal Measures of the Mid-Continent region are full of mica in places and also other minerals of igneous rocks. The sources of these minerals are not known. Was the source the Rockies, the St. Francis Mountains of Missouri, the igneous rocks of the Lake Superior region and Ontario, the Arbuckle and Wichita

[8] Trask, P. D., Origin and environment of source sediments of Petroleum: *Am. Petroleum Inst.*, 1932.

mountains, or did they come from regions not yet discovered because of being buried beneath later sediments? The Chester series of the Mississippian of Indiana in some beds has a large variety of detrital minerals. Studies show these were not derived from the Wisconsin area and that an igneous terrane was the source. The sandstones of the Pennsylvanian of the Illinois-West Kentucky Coal Basin in some instances are covered with mica flakes which were certainly derived from igneous rocks. Appalachia has been postulated as the source. Studies of these and other sediments may reveal possibilities in the way of subsurface geology which at present are undreamed. Hand in hand with the study of the minerals of sediments should go studies of the minerals of igneous rocks in order to learn what resistant minerals each igneous terrane contains. The time-honored method of thin-section study will not suffice, as that method shows little more than the dominant minerals and textures. Samples of several pounds must be taken from all phases of an igneous body, each sample must be crushed, and all its minerals, even the most rare, determined. This information will permit relating the minerals of sedimentary rocks to one or more of the sources and if none of the sources can supply the minerals, then an unknown source must exist. Unless this field of sedimentary geology is sidetracked by something more important, or more fashionable, it may be expected to yield results of great importance to geology within the next couple of decades.

UNCONFORMITIES

A problem that has vexed geologists for a long time is that of unconformities, or breaks in deposition. Up until less than twenty years ago nearly every break in deposition had its development referred to emergence from beneath the sea, at which time the rocks below the unconformity constituted the surface materials of a land area. Glimmerings of a different possibility began to be apparent about thirty years ago, but it remained for the late Joseph Barrell in 1916 and for Douglas Johnson and other marine physiographers to point out that in the sea a position of the bottom eventually is reached whereon it is impossible for permanent deposition to be accomplished, and when that position is attained permanent deposition is finished and whatever may be deposited there is reduced to a fine condition by scavengers and ultimately moved to deeper water. Not all geologists acquired these teachings of Barrell and Johnson but the former makes it very definite in his long paper on the *Rhythms and the Measurement of Geologic Time*. This position of the bottom is the profile of equilibrium and its lowest position is the base level of deposition. When a bottom is below the profile of equilibrium it will be built up to it by deposition: when above it will be reduced to that level by erosion. That such a level exists can not be questioned —it may be seen on some parts of our existing shallow sea bottoms—and we have evidence beneath the sea of places where the surface materials are of Tertiary age. The extent of a sea bottom reaching the profile of equilibrium would be greatest toward the end of a long period of base leveling and stability. Hitherto, unconformities have been referred by most geologists to subareal erosion following emergence, but it seems absolutely certain that many are due to the bottoms having been built to the profile of equilibrium with succeeding cessation of deposition until a change took place bringing this profile to a different level. This may be done by conditions in the sea or on the adjacent land. There remain to be established criteria by which unconformities developed on land may be distinguished from those developed beneath the sea. At present our paleogeography is based on the idea that unconformities are of land origin and if many of them were developed beneath the sea and were not made during an emergence it follows that some of the paleogeography may be more or

less incorrect. However, until criteria of differentiation are established separation of these two types of unconformities is not possible. Here remains a fertile field for discoveries in the future and it is difficult to state its possibilities.

SUMMARY

This is the present position. Sediments and all connected with them are being studied and should be studied as products of environmental conditions. They are not simple substances as originally thought; they are the results of long chains of complex processes. Every sedimentary particle and its associations represent all that exists of a past environment. They are not dead substances but fragments of ancient history of which the reading is destined to make necessary the rewriting of much geologic history and the redrawing of much ancient geography. The unconformities and stratigraphic breaks in the sequence of sediments can not all be considered resultants of emergence and subareal erosion. Some of them were developed without emergence and some of them probably developed as a consequence of rise of sea level.

Each sedimentary product constitutes a distinct problem. The day is past when one may state that a given sedimentary product is of a given origin because a similar product is of that origin. One dare no longer state that because a given limestone is of marine origin, all limestones are of marine origin, because a given chert resulted from weathering that all cherts are probably of that origin, because a given sandstone was rapidly deposited that all sandstones were rapidly deposited. When an explanation of origin has been developed from the study of a particular sediment, the *explanation applies only to that sediment and to no other* and it is poor science to apply the explanation to another sediment of a similar character. Because a *raw sediment* has a given composition does not justify assuming that the finished product will have the same composition since the *raw sediment* may undergo such profound changes as to change completely its composition. A *raw sediment* composed of carbonate and organic matter with a small content of phosphate or silica may give rise to a sediment dominantly phosphatic or dominantly silicious and containing little organic matter or little carbonate. The character of the *raw sediment* may little indicate the character of the finished product.

Generalization is a common human tendency and it also is a dangerous one. It is a tendency of inexperience as much as anything, and was widely prevalent among the early leaders of the science. Werner was a splendid example. The older textbooks of geology are full of generalizations which for many years have passed for facts. Some are known to be incorrect and it is probable that most of them need modification. Every generalization should be questioned to determine its factual basis.

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SOME RECENT AND FOSSIL BRACKISH TO FRESH-WATER FORAMINIFERA

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ABSTRACT

Certain species of arenaceous and calcareous foraminifera occur in waters of very low salinity in Venezuela. These forms are also known in the same region from Tertiary sediments which for other reasons have been suspected of brackish water origin. Consideration of both recent and fossil occurrences permits conclusions on the ecology of these species and the consequent interpretation of the depositional environment of sediments in which they occur.

It is commonly accepted that foraminifera with tests suited to fossilization are confined to marine waters or brackish[1] waters closely associated with the open sea.[2] This assumption influences to a great extent the interpretation of past environments by means of fossil foraminifera. However, there seem to be few actual data on the limiting salinity of waters in which various species can live. It may, therefore, be worth while to record some local observations on the occurrence of certain arenaceous and calcareous species in waters of known low salinity and to consider the associations of these same forms in the Tertiary sediments of the region.

OCCURRENCE OF *QUINQUELOCULINA FUSCA* BRADY IN TAP WATER AT MARACAIBO

The writer has frequently noticed the presence of *Quinqueloculina fusca* H. B. Brady in tap water at the Venezuela Gulf Terminal in Maracaibo, Venezuela. This water is pumped from the lake in the immediate vicinity of the terminal, which is situated on the Strait of Maracaibo, more than 30 kilometers from the marine waters of the Gulf of Venezuela. (See Fig. 1.) The fauna and flora of the lake here are abundant; sieving of the tap water yields, in addition to *Quinqueloculina fusca*, living ostracodes, copepods, micromollusks, algae, diatoms, etc.

The salinity of the lake water at this point is variable with the season and the year. The following analyses from Maracaibo and vicinity are available:[3]

[1] The word "brackish" is here used to indicate water which is distinctly salty but less so than normal sea water.

[2] Cushman mentions the finding of arenaceous foraminifera by Daday in salt pools of Hungary, and the recording by Brodsky of various calcareous species in springs in central Asia. Cushman, J. A., Foraminifera, their classification and economic use, 2d edition, p. 44, 1933.

[3] Since the preparation of this manuscript additional total salinity determinations have been made as follows:

March 21, 1934, Ven. Gulf Terminal	3,810
April 1, 1934, Ven. Gulf Terminal (high tide)	3,589

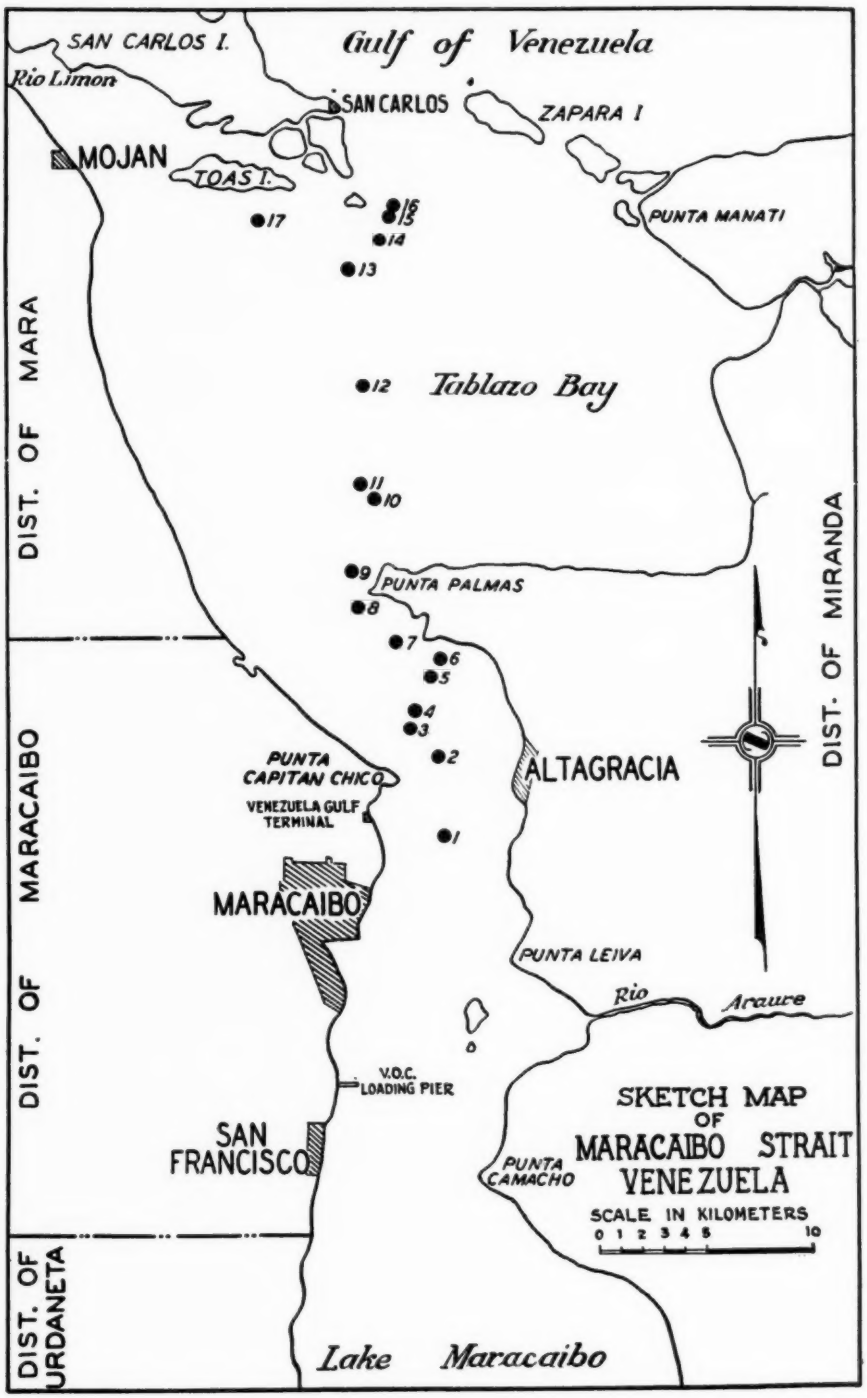
SAN CARLOS I.
Gulf of Venezuela
Rio Limon
SAN CARLOS
ZAPARA I
MOJAN
TOAS I.
PUNTA MANATI
17
16
15
14
13
12
Tablazo Bay
11
10
9
PUNTA PALMAS
8
7
6
5
4
3
2
1
DIST. OF MARA
DIST. OF MIRANDA
PUNTA CAPITAN CHICO
VENEZUELA GULF TERMINAL
ALTAGRACIA
MARACAIBO
DIST. OF MARACAIBO
PUNTA LEIVA
Rio Araure
V.O.C. LOADING PIER
SAN FRANCISCO
PUNTA CAMACHO
SKETCH MAP OF MARACAIBO STRAIT VENEZUELA
SCALE IN KILOMETERS
0 1 2 3 4 5 10
DIST. OF URDANETA
Lake Maracaibo

FIG. 1

Analyses of Lake Water from Maracaibo and Vicinity

Date	Total salinity in parts per million
May, 1921	2,300 (McNab)
September, 1922	600 (McNab)
January, 1925	530 (McNab)
February, 1930, Ven. Gulf Terminal	1,000 (Bopp)
January, 1934, Ven. Gulf Terminal	1,100 (Sass) (chlorides only)
February, 1934, Ven. Gulf Terminal (high tide)	1,146
February, 1934, Ven. Gulf Terminal (low tide)	1,094

The presence of *Quinqueloculina fusca* in the tap water here has been recorded definitely by the writer only in February of 1930 and January and February of 1934. However, it has been noted casually at various times and it is probable that the species lives the year around in the vicinity of Maracaibo. In any case, it is definitely established that during some months it exists here in water of less than one-thirtieth the salinity of normal sea water.

The collected specimens are buff-brown in color, with fine angular sand grains set in a non-calcareous chitinous (?) matrix. They agree closely with published descriptions of the species.

BOTTOM SAMPLES FROM MARACAIBO STRAIT, VENEZUELA

During November, 1929, the writer, in company with C. W. Flagler, H. S. Ladd, and others, collected seventeen bottom samples over a distance of 30 kilometers in the Strait of Maracaibo between the city of Maracaibo and the outlet of the lake into the Gulf of Venezuela at San Carlos. (See Fig. 1.) A number of water samples were collected at the same time for salinity determinations.

The so-called *Lake* of Maracaibo is a large inland body of water connected with the Caribbean Sea (Gulf of Venezuela) by a narrow neck nearly 50 kilometers in length. The total area of the lake is approximately 20,000 square kilometers; its maximum depth less than 150 feet. Many large rivers empty into the lake, especially near its southern end, and the surface water throughout the lake proper is sufficiently fresh to be potable. (There is a possibility of a concentration of salt in the bottom waters of the deeper parts of the lake.) A considerable current of fresh water escapes into the sea through the long neck, Maracaibo Strait, particularly during the rainy season. On the other hand, semidiurnal tides, which have a range of as much as 2 feet at the city of Maracaibo, probably affect the salinity of the northern part of the strait to some extent.

Determinations of total salinity were made by Anton Bopp on the water samples from six stations. These are shown below in comparison with a sample from the Gulf of Venezuela, taken on the shores of Paraguana Peninsula.

April 1, 1934, Ven. Gulf Terminal (low tide).....3,530
These determinations, made near the close of the dry season, are believed to represent approximately the maximum salinity for the water of this locality.

Analyses of Water from Maracaibo Strait and Gulf of Venezuela

Station No.	Total salinity in parts per million
1	1,010
6	935
8	1,170
10	1,150
13	1,150
14	1,100
Gulf of Venezuela	39,460

It should be mentioned that these samples were taken during the latter part of the rainy season when the maximum current of fresh water might be expected to be moving seaward through the strait. Also, most of the samples were taken at low tide, and it is possible that the salinity at Stations 13 and 14 might be somewhat increased at high tide. Nevertheless, it seems probable that maximum salinity throughout the range of sample stations never exceeds a very small fraction of that of normal sea water.

All water samples were taken at the surface. The possibility of stratification of water according to salinity was considered but this is believed improbable in the shallow waters of the strait where current and wave action must nearly everywhere reach the bottom.

The locations of bottom samples are shown on Figure 1. Almost all samples consisted of buff to gray silt or sand. Depths of samples 1 to 8 averaged 30 to 40 feet; samples 9 to 17 averaged 10 to 20 feet.

Six samples showed no life forms other than an abundance of diatoms (Stations 1, 4, 5, 7, 8, 15). The sample from Station 13 was entirely barren. All other stations showed foraminifera of some sort. It is of interest that none of the samples containing diatoms showed foraminifera.

Samples from Stations 2, 3, 6, and 9 showed only specimens of *Trochammina* sp., and *Haplophragmoides* sp. The microfaunas of other stations were as follows:

Station 10
- *Globigerina* sp. (one specimen)
- *Haplophragmoides* sp.
- *Trochammina* sp.

Station 11
- *Cyclammina* sp.
- *Haplophragmoides* sp.
- *Quinqueloculina fusca* H. B. Brady
- *Textularia* sp.
- Ostracodes

Station 12
- *Bulimina* sp.
- *Trochammina* sp.
- *Haplophragmoides* sp.
- *Uvigerina* sp.

Station 14
- *Elphidium* sp.
- *Haplophragmoides* sp.
- *Rotalia beccarii* (Linné) (one broken specimen)
- *Trochammina* sp.

Station 16
- *Globigerina* sp.
- *Trochammina* sp.
- Ostracodes

Station 17
- *Bigenerina* sp.
- *Haplophragmoides* sp.
- *Rotalia beccarii* (Linné) (common)
- Ostracodes

Foraminifera from the bottom samples may be divided into three general groups.

1. Arenaceous types belonging to the Lituolidae, Trochamminidae, and Textulariidae. Specimens belonging to this group were found in all stations having fauna of any sort. Some are fairly well-preserved but

explanation of their occurrence here is not clear. Possibly this is their natural habitat; more probably they are largely detrital forms from Tertiary sediments of the lake basin.

2. Pelagic or relatively inflated types such as *Globigerina*, *Bulimina* and *Uvigerina*. These occur only in the northern, seaward half of the traverse. The occurrence of well preserved specimens of *Globigerina* sp. in relatively fresh water is most reasonably explained as a result of transportation by tidal currents. The same explanation may be extended to the *Bulimina* and the *Uvigerina*.
3. Recognized brackish or shallow water foraminifera. *Quinqueloculina fusca* H. B. Brady was noted at Station 11, *Elphidium* sp. at Station 14, and *Rotalia beccarii* (Linné) at Stations 14 and 17. The excellent preservation of these forms eliminates the possibility of their being detrital and their abundance also strongly suggests that they were collected from their natural habitat. The shallowness of the water at all of these stations precludes the possibility of salinity stratification so that the surface salinity data from Station 14 (1,100 parts per million) is believed to be approximately representative for all of these stations under the existing seasonal and tidal conditions.

Quinqueloculina fusca is widely known as a brackish water species and *Rotalia beccarii* and species of *Elphidium* have often been reported from stagnant or very shallow marine coastal waters. The occurrence of *Quinqueloculina fusca* at Station 11 is further evidence that it is not only a brackish water species but also that it may live in very nearly fresh water. Similarly, it seems that *Rotalia beccarii* and *Elphidium* sp. may also survive in waters of low salinity, although it is noteworthy that they were not found as far lakeward as was *Quinqueloculina fusca*.

BOTTOM SAMPLES FROM NORTHERN END OF LAKE MARACAIBO VENEZUELA

A number of bottom samples were collected in February, 1934, along the loading pier of the Venezuela Oil Concessions, Ltd., about 7 kilometers south of Maracaibo, on the west side of the lake at its northern end. (See Fig. 1.) Samples were taken at points 800, 600, 400, and 200 meters from shore at depths of 12, 10, 9, and 7 feet respectively. These showed an abundance of mollusks and a few specimens of ostracodes and of *Quinqueloculina fusca* H. B. Brady. There were also some arenaceous foraminifera, probably of detrital origin. The average of four total salinity determinations here was 999 parts per million. At the end of the pier determinations were made both for surface water and for water from the bottom (depth 12 feet). These gave a difference of less than 50 parts per million so it is evident that there is no salinity stratification in the shallow water of this part of the lake. The well preserved specimens of *Quinqueloculina fusca* in the bottom samples here are believed to have been native to this environment.

FORAMINIFERA FROM SALINA SAUCO, VENEZUELA

Salina Sauco is a large lagunal area on the northeastern coast of the

State of Falcon, Venezuela, connected periodically with the Caribbean Sea through a narrow opening in a barrier sand bar but supplied with fresh water by *quebradas* at its southern end. No salinity determinations are available on the waters of the *salina* but at least during certain seasons they are much less saline than the waters of the open sea. The *salina* muds yield specimens of *Rotalia beccarii* (Linné) and *Nonion* sp.

FORMINIFERA FROM TERTIARY BRACKISH WATER SEDIMENTS

Much of the thick Upper Tertiary section of Venezuela is apparently of brackish to fresh-water origin. Deposition in environments not truly marine is suggested locally by abundance of lignites and carbonized plant debris; clays mottled in reds, yellows, and light grays; profusion of siderite spherules; low chloride content of shales and clays; absence of marine and presence of brackish water mollusks. Sediments of this type are generally barren of foraminifera, but during several years of investigation of well and outcrop samples from these formations a considerable number of occurrences have been noted. *Quinqueloculina fusca* H. B. Brady, *Rotalia beccarii* (Linné), *Trochammina* sp., *Haplophragmoides* sp. and *Ammobaculites* sp. are definitely known from these sediments.

The writer has recorded some 45 distinct occurrences of *Quinqueloculina fusca* in the Miocene and Pliocene sediments of Venezuela. The fossil form is white, finely arenaceous and usually much flattened, due to the fact that the sand particles of the test are mounted in a flexible chitinous matrix. Almost all occurrences are in sediments which from lithologic or other paleontologic evidence have been suspected of brackish water origin. In twenty-eight cases *Quinqueloculina fusca* was unaccompanied by other foraminifera; in five cases it was associated only with *Rotalia beccarri;* in eleven cases it was accompanied only by species of *Haplophragmoides;* and in one case *Quinqueloculina fusca*, *Rotalia beccarii*, and *Haplophragmoides* sp. were found together.

Rotalia beccarii (Linné) is so common in the Miocene and Pliocene sediments of Venezuela that enumeration of occurrences is futile. As mentioned above, there are five cases where it occurs alone with *Quinqueloculina fusca* and one case where it is associated with both *Quinqueloculina fusca* and *Haplophragmoides* sp. The writer has recorded five occurrences alone with *Haplophragmoides* sp. and many samples show *Rotalia beccarii* unaccompanied by other foraminifera. Generally, however, it is associated with species of *Elphidium* and *Nonion;* somewhat less frequently with species of *Textularia*, *Eponides*, *Cibicides*, and various miliolid genera.

Species of *Haplophragmoides*, *Ammobaculites*, and *Trochammina* have often been noted in the supposedly brackish water Miocene sediments. These are occasionally associated with *Quinqueloculina fusca* and *Rotalia beccarii*, as mentioned above, but are more commonly unaccompanied by other foraminifera. Species of these same genera, of course, are also present in the definitely marine Miocene sediments.

The writer has never found *Quinqueloculina fusca* in Eocene or older sediments and has only rarely encountered *Rotalia* aff. *beccarii* in sediments believed to be older than Oligocene. However, species of *Haplophragmoides*, *Ammobaculites*, and *Trochammina* are characteristic of great thicknesses of sandy shales and interlaminated sandstone and shale of Eocene and Cretaceous age in Venezuela which are otherwise barren of foraminifera. Pure shale bodies (deeper water origin ?) associated with these sediments frequently carry more varied, definitely marine, calcareous and arenaceous foraminiferal faunas. Much of the interlaminated sandstone and shale is probably of deltaic or estuarine origin and is believed to have been deposited in water of less than normal sea water salinity. The possibility of the removal of originally calcareous forms through solution is precluded by the common presence of calcareous ostracode shells. The limited variety of the fossil fauna seems to be due rather to an environment of deposition unfavorable for the development of a typical marine foraminiferal fauna. That low salinity of the depositing medium may have been an important factor is suggested.

SIGNIFICANCE OF CERTAIN FORAMINIFERA WITH REGARD TO SALINITY

As a result of observations made on both recent and older sediments, conclusions may be drawn concerning the ecology of certain foraminiferal species in the Venezuelan region.

Quinqueloculina fusca H. B. Brady is commonly a brackish to fresh-water species. It may live in water of less than one-thirtieth the salinity of normal sea water and evidently prefers brackish water to a marine environment. Its presence in any abundance in Tertiary sediments of the region suggests estuarine or deltaic origin, or at least deposition in water of less than normal marine salinity. The fact that it is usually found alone suggests that it is able to live in water so nearly fresh as to be uninhabitable to other foraminifera with tests suitable for preservation.

Rotalia beccarii (Linné) is a brackish water to marine species. It may live in waters of low salinity but is also common in definitely marine waters. Its presence in sediments of the Venezuelan region suggests either shallow water marine or brackish water environment. In shallow water it is commonly associated with species of *Elphidium*, *Nonion*, *Textularia*, *Cibicides*, and various miliolid genera. When occurring alone or with *Quinqueloculina fusca*, brackish water is indicated. However, it cannot live in water of as low salinity as can *Quinqueloculina fusca*.

Haplophragmoides, *Ammobaculites*, *Trochammina* and perhaps other arenaceous genera have had representatives in brackish water as well as in truly marine environments. Species of these genera show a wide range in habitat from deep sea to shallow marine and brackish water. Records of their presence in existing brackish waters of the region are not definite, but fossil occurrences indicate the ability of some of the Tertiary forms to live in such an environment. Certain Miocene spe-

cies seem to have lived in water of lower salinity than that in which *Rotalia beccarii* could exist.

SOME PREVIOUSLY PUBLISHED ECOLOGICAL DATA ON THE FORAMINIFERA CONSIDERED IN THIS PAPER

With the library facilities available to the writer, an exhaustive review of the literature on brackish water foraminifera cannot be made, although such an undertaking would be highly desirable.

Quinqueloculina fusca Brady has been described frequently from brackish waters in the vicinity of the British Isles. Cushman and Valentine[4] have noted the species in shallow water near the Channel Islands of Southern California. Cushman and Parker[5] found *Quinqueloculina fusca* in Rio de Janeiro harbor. There are also a number of records of fossil occurrences. Definite data are lacking on the salinity of waters from which the species has been collected, but the Southern California occurrence, at least, seems to have been in normal sea water.

Varieties of *Rotalia beccarii* (Linné) are widely known as inhabitants of warm shallow waters. That they also have been found in waters of low salinity seems probable. Cushman[6] notes the occurrence of *Rotalia beccarii* in "warm shallow stagnant water" in the Tortugas region. Natland[7] found *Rotalia beccarii* abundant in a "shallow brackish water lagoon" in Southern California.

There seem to be few published data to indicate that the arenaceous genera *Haplophragmoides*, *Ammobaculites*, and *Trochammina* may live in brackish water. On the contrary, these genera have most frequently been described from the deep seas, although their locally common occurrence in shallow waters is also known. Norton,[8] in his work on bottom samples from the Florida and West Indies region, found *Haplophragmoides* limited to depths greater than 680 fathoms and *Trochammina* most common in deep water. *Ammobaculites* sp. was found in shallow water, however. Hanna and Church[9] state that *Trochammina inflata* (Montagu) "is found in the shallower portions of open bays and is able to live in brackish water."

Norton's[10] work in the West Indian region substantiates the idea that the assemblage of *Rotalia beccarii* and species of *Elphidium*, *Nonion*, *Textularia*, *Cibicides*, and *Quinqueloculina* in the Miocene sediments of Venezuela is indicative of deposition in warm shallow water.

[4] Cushman, J. A., and Valentine, W. W., Shallow water foraminifera from the Channel Islands of Southern California: *Dept. Geol. Stanford Univ., Contr.*, vol. 1, p. 9, 1930.

[5] Cushman, J. A., and Parker, F. L., Recent foraminifera from the Atlantic Coast of South America: *U. S. Nat. Mus., Proc.*, no. 2903, p. 3, 1931.

[6] Cushman, J. A., Shallow water foraminifera of the Tortugas region: *Carnegie Inst. Washington, Pub.* 311, pp. 52–53, 1922.

[7] Natland, M. L., The temperature- and depth-distribution of some recent and fossil foraminifera in the Southern California region: *Scripps. Inst. of Oceanography, Bull., Tech. Ser.*, vol. 3, no. 10, p. 227, 1933.

[8] Norton, R. D., Ecologic relations of some foraminifera: *Scripps Inst. of Oceanography, Bull., Tech. Ser.*, vol. 2, no. 9, 1930.

[9] Hanna, G. D., and Church, C. C., A collection of recent foraminifera taken off San Francisco Bay, California: *Jour. Paleontology*, vol. 1, no. 3, p. 201, December, 1927.

[10] Norton, R. D., Op. cit.

JOURNAL OF PALEONTOLOGY, VOL. 8, NO. 4, PP. 477–479. DECEMBER, 1934

A COPROLITE HORIZON IN THE PENNSYLVANIAN OF CHAFFEE AND PARK COUNTIES, COLORADO

J. HARLAN JOHNSON
Colorado School of Mines, Golden, Colorado

ABSTRACT

Coprolites have been found abundantly in a zone about 65 feet thick. The zone is in the Weber formation of Pennsylvanian age commencing about 1,100 feet above the base of the Pennsylvanian. The coprolites are bullet-shaped cylindrical masses, averaging about 1.62 cm. long and 0.64 cm. wide. Many show a definite spirally coiled structure.

Their structure, composition, nature and relationships are discussed. It is concluded they belong mainly to ganoid fishes of the genus *Paleoniscus*.

Coprolites were found by the writer during the field season of 1930 and again in 1933 when more detailed studies of the Pennsylvanian showed them to occur at the same stratigraphic horizon at a number of localities. Several thousand specimens were collected, detailed stratigraphic sections measured, and the zone was traced for a number of miles.

Location.—Outcrops of the horizon have been found along the western and southwestern sides of South Park in Park County, Colorado, and in the adjoining valley of Trout Creek in Chaffee County.

Geological Occurrence.—The coprolite horizon is in the upper portion of the so-called Weber formation[1] of Pennsylvanian age. Along Trout Creek the base of the horizon is about 1,400 feet above the Mississippian-Pennsylvanian contact. The coprolites occur throughout a zone about 65 feet although they are most abundant in the upper 30 feet of the zone. The beds consist mainly of black shales. Some of the layers are slightly calcareous and a few thin zones of shaly limestone and calcareous nodules occur in the shales. The coprolites, however, are found only in the black shales. They are somewhat silicified and weather out freely.

Land plants of late Pottsville type and marine invertebrates have been obtained from the lower 500 feet of the Weber formation in this region. Fragments of Productus shells and impressions of pelecypods and byrozoans have been found within a hundred feet of the coprolite horizon.

Description of the Coprolites.—The coprolites consist of bullet-shaped cylindrical masses, more or less rounded at the ends. Many show a definite spirally coiled structure (Fig. 1). In color they are lead-gray to black. There is considerable variation in size but measurements of over a hundred specimens average approximately 1.62 cm. long and 0.64 cm. thick. Nearly all the specimens are flattened, apparently by compression of the shales. Polished cross sections also show evidence of a spiral structure. A microscopic study of the specimens and polished sections showed them to be composed of carbonized fragments of bone, scales, teeth, and shell fragments imbedded in a ground mass of mud, all somewhat silicified.

Chemical Analysis.—Mr. F. G. Hills of the Colorado School of Mines Experimental Plant ran analyses of several

[1] For a discussion of the nomenclature see Johnson, J. H., *U. S. Geol. Survey, Prof. Paper* 185, pt. B, 1934.

FIG. 1—Pennsylvanian coprolites from Colorado, ×2.

specimens of coprolites. They averaged as follows:

	Per cent
SiO_2	33.4
Al_2O_3	20.1
Fe_2O_3	26.5
CaO	2.5
MgO	8.3
P_2O_5	1.55
Ignition (Organic)	7.5
	99.85

Associated fossils.—Ganoid scales, a few fish vertebra and some tubular algal masses, include all the fossils which have been found associated with the coprolites. The scales are rhomoboidal in outline and highly enameled. The surface is smooth on some specimens, and faintly striated on others. A few show a granulated surface. They measure approximately 0.85 by 1.2 centimeters.

Comparison.—It is interesting to compare both the coprolites and their occurrence with those from the West Virginia coprolite horizon described by Price.[2] Stratigraphically the deposits are of nearly the same age. At both places the coprolites occur in black shales associated with fish remains. The recognizable Colorado fish material represents scales of ganoids. The majority of the Colorado coprolites in appearance, dimension and the number and spacing of the coils (3 to 5) are practically identical with those Price ascribes to ganoids of the genus *Paleoniscus*. A few of the coprolites have a larger number of closely spaced coils which suggest those ascribed to sharks. The illustrations shown of the West Virginia specimens look exactly like Colorado material. The chemical compositions, however, are quite different, the Colorado specimens being much higher in SiO_2 and Al_2O_3 and much lower in $CaCO_3$ and $Ca_3(PO)_2$ than the West Virginia coprolites. The specimens are considerably silicified which suggests that much of the silica may have been introduced after burial. The aluminia, however, seems to represent mud taken in with the food.

[2] Price, P. H., *Annals Carnegie Mus.*, vol. 17, no. 2, pp. 211–254, pls. 10–21, 1927.

PALEONTOLOGICAL NOTES

DANGER OF INHALING THE VAPOR OF CARBON TETRACHLORIDE[1]

LLOYD G. HENBEST
U. S. Geological Survey, Washington, D. C.

Carbon tetrachloride has been used extensively in recent years as a heavy liquid for separating foraminifera from sand, silt, or marl by flotation. The advantages of this liquid are its cleanness, low cost, evaporation rate, non-inflammability, and the supposedly harmless character of its vapor wherever its concentration is insufficient to cause suffocation.

Believing that the vapor is harmless when inhaled, many, including the writer, have not made more than ordinary provisions for ventilation. I have known of the use of this liquid in poorly ventilated rooms. Recently my attention has been directed to a growing opinion among medical scientists that the ingestion or inhalation of carbon tetrachloride may produce serious degeneration of kidney and liver tissues. Wishing for more definite information on this subject a request was sent to the Surgeon General of the U. S. Public Health Service for a statement that might be published or for a reference to a report that is generally acceptable. His reply follows:

My dear Mr. Henbest:

Your letter of July 17 addressed to the Surgeon General, U. S. Public Health Service, and requesting information as to the possible hazard in breathing carbon tetrachloride vapor, has been referred to me for reply.

I regret that the Public Health Service has no publications for distribution dealing with this subject. The following statement is made from the literature.

The action of carbon tetrachloride is similar to that of chloroform. Its general action is that of an anesthetic. If breathed in sufficient concentration it may cause damage to cells of the liver and degenerative changes in other tissues. Dr. Lehmann of the University of Wurzburg has reported that 1,600 parts per million produce no reaction after several hours, which probably refers to a single exposure. Where the exposure is much prolonged or repeated the maximum safe concentration is much less. Passed Assistant Surgeon F. R. Brunot, U S. Public Health Service, places it at 200 parts per million, on the basis of animal experimentation and observations in a limited number of dry cleaning establishments. Dr. Brunot also states that where the odor of carbon tetrachloride is pronounced, the concentration very likely exceeds 200 parts per million, and recommends that measures should be directed to eliminate the fumes.

Down-draft exhaust ventilation, where practicable, is advised, as this controls the carbon tetrachloride at its source. There should always be good general ventilation. In instances where high concentrations can not be avoided, a canister type of gas mask containing activated charcoal is suggested.

By direction of the Surgeon General.

Respectfully,

[Signed] L. R. THOMPSON
Assistant Surgeon General,
Chief, Scientific Research Division.

Since many laboratories are equipped with ordinary hoods, but not with down-draft ventilators, it seems most practicable in obtaining good ventilation to equip the hood for forced draft during summer use. During the winter the natural draft will probably provide adequate ventilation. Besides using an electric fan, a good draft can frequently be obtained by heating the air in a hood by a gas burner. If the air current is sufficient, the vapor of the carbon tetrachloride will probably not extinguish the flame.

[1] Published by permission of the Director, U. S. Geological Survey.

PUBLICATIONS GRANT FROM THE NATIONAL ACADEMY OF SCIENCES

The Journal of Paleontology acknowledges with cordial appreciation a grant from the National Academy of Sciences in the amount of $750.00, which has been used to enlarge this volume of the Journal of Paleontology. This has provided means of publication of researches in paleontology that otherwise would have been considerably delayed. On behalf of the Society of Economic Paleontologists and Mineralogists, the efforts of Dr. T. Wayland Vaughan, associate editor of the Journal, are to be credited mainly for action leading up to this grant.

ERRATA

In "The Genus *Diploschiza* from the Upper Cretaceous of Alabama and Texas," by Lloyd William Stephenson, Journal of Paleontology, September, 1934, page 279, left-hand column, line 16 from top, the U. S. Geol. Survey collection number 16242 should be 16424.

REVIEWS

Wetzel, Otto, Die in organischer substanz erhaltenen Mikrofossilien des baltischen Kreidefeuersteins mit einem sediment-petrographischen und stratigraphischen Anhang (Microfossils preserved as organic substance in Baltic Cretaceous flints, with a sediment-petrographic and stratigraphic appendix): Palaeontographica, vol. 77, pp. 141–186; vol. 78, A, pp. 1–110, pls. 1–7, Stuttgart, E. Schweizerbart'sche Verlagsbuchhandlung, 1933.

This paper deals mainly with the remains of the organic substance of Protozoa or of forms that the author interprets as Protozoa. Many geologists will perhaps be surprised to find fossilized organic substance of Protozoa affording the material for a monograph. Most of us probably think of Protozoa—except the Foraminifera and Radiolaria—as little masses of jelly, about the last thing one would expect to find fossilized. But consultation of a general treatise—the Cambridge Natural History, for instance—discloses the fact that there is hardly a larger group among the Protozoa that does not contain forms with harder envelopes, plates, or spicules of chitin, undetermined chitin-like substance, silica, or calcium carbonate. It is, furthermore, revealing to learn from the paper itself that the study of such forms is not even new—that it goes back as far as 1833, when the famous diatomist Ehrenberg published descriptions of some of these forms, and that since then there have been several papers dealing with them, including one by M. C. White on microscopic organisms in the siliceous nodules of the Paleozoic rocks of New York in the American Journal of Science and Arts for 1862. In this paper White suggests that there is here a line of investigation that is worth following up—a suggestion on which his countrymen have apparently not acted. In recent years the principal contribution has come from Wilhelm Wetzel, a sedimentary petrographer, in connection with his petrographic study of flints, published in 1922.

The work on which the present paper is based consisted in studying under the microscope, by transmitted light, more than 15,000 thin slivers chipped from flints, in dissolving some of these in hydrofluoric acid and making tests of the organic residue, and in studying about 100 thin sections.

The largest number of forms described by the author belong to two groups. One is the flagellates. The definiteness and distinctness of many of these is striking and leaves little doubt that they can be pretty closely identified with living genera of this class. But it is rather surprising to find structures as delicate as the flagellae preserved attached to the organisms to which they belonged.

The other principal group consists of more or less spherical bodies with appendages of various and definite forms. Members of this group were regarded by Ehrenberg in 1838 as zygospores of the Desmidaceae. More recently they have been regarded as copepod eggs. The present author gives them the noncommittal name "Hystricosphaeridae" (porcupine spheres) and, after careful consideration of a great variety of plant and animal forms, reaches the conclusion that they are probably Protozoa closely related to the flagellates or to radiolarian-like rhizopods—perhaps transition forms between the two. This is the only group described by him of which the remains are found in any abundance in the residue left by solution of the associated chalk in acid, and he notes the occurrence of similar forms in the acid residue of Silurian and Devonian limestones. It is, also, forms like these that were described by White in 1862.

From the occurrence in the flint of so many delicate forms that are scarce or lacking in the surrounding chalk the author concludes that the flint was prob-

ably formed soon after the deposition of the chalk, though on this as on other questions his conclusions are stated with caution and temperance. The paper leaves the impression of being a very conscientious and painstaking piece of work, and it can probably be safely asserted that the investigation is by far the most extensive and most important that has been made in this field. If the results are not as unprecedented as they may seen at first, they nevertheless, on account of their extent and thoroughness, promise to open up important and neglected possibilities for biology, stratigraphy, and micropaleontologic correlation.

MARCUS I. GOLDMAN
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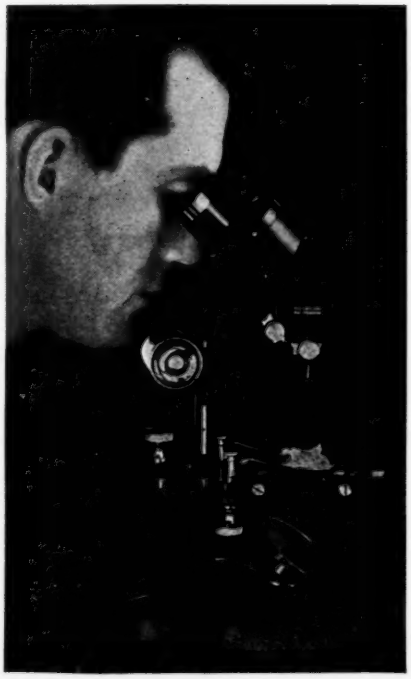

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